FEBRUARY 1960
Volume 194 Part 2

Established 1869
Incorporated by Royal Charter 1899

Tempering characteristics of low-carbon low-alloy steels
K. J. Irvine and F. B. Pickering 137

Changes in mechanical properties of steels caused by fatigue stressing
G. F. Modlen and G. C. Smith 154

Kinetics of first-stage graphitization in Fe–C and Fe–Co–C alloys
A. S. Appleton 160

Constitution of iron–niobium–silicon system *H. J. Goldschmidt* 169

Stress corrosion of austenitic stainless steel by high-temperature solutions
P. P. Snowden 181

Accuracy of point counting in metallographic investigations
T. Gladman and J. H. Woodhead 189

Spectrographic determination of residual elements in steel by the excitation index technique *K. M. Bills* 193

Determination of trace elements
N. W. H. Addink 199

Gaseous reduction of fine iron ores
S. Y. M. Ezz and R. Wild 211

Liquidus–solidus relations in the system Fe–Al *J. R. Lee* 222

Developments in electrical equipment for reversing plate mills
H. S. Brown and A. P. Baines 225

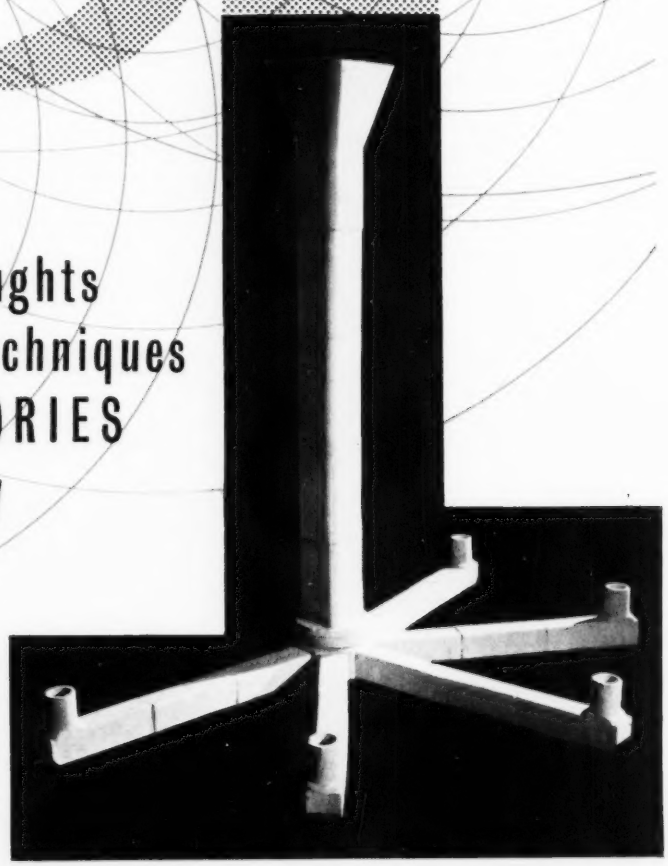
Some aspects of plate-mill design and layout *A. Marshall* 240

News 249 Abstracts 253

A full list of contents is given on the Title Page (see page 71 of the Advertisement Section)

JOURNAL OF THE IRON AND STEEL INSTITUTE

when to-day's thoughts
become to-morrow's techniques
DYSON REFRACTORIES
will be ready



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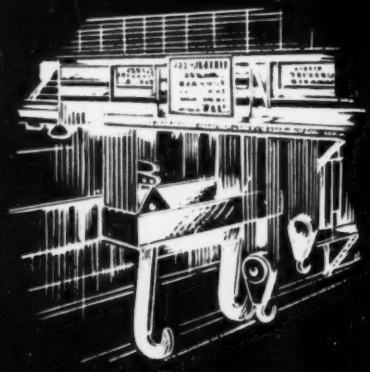
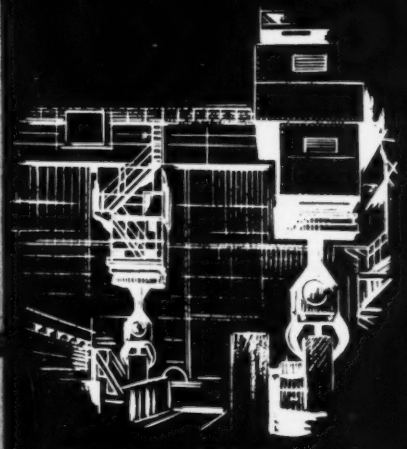
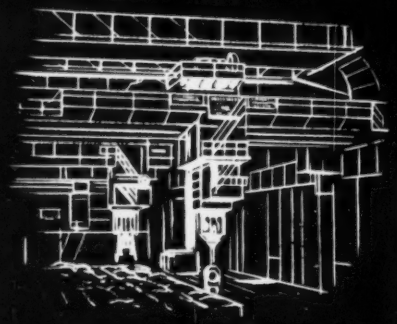


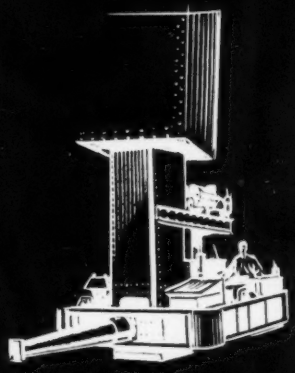
Ladle Cranes



Soaking Pit Cranes



Stripping Cranes



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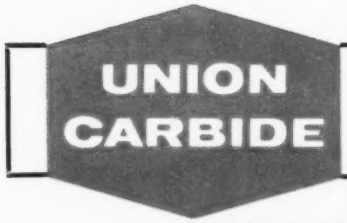

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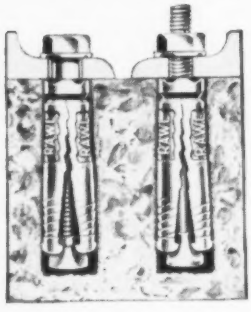

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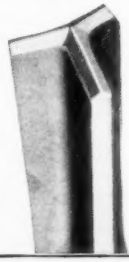

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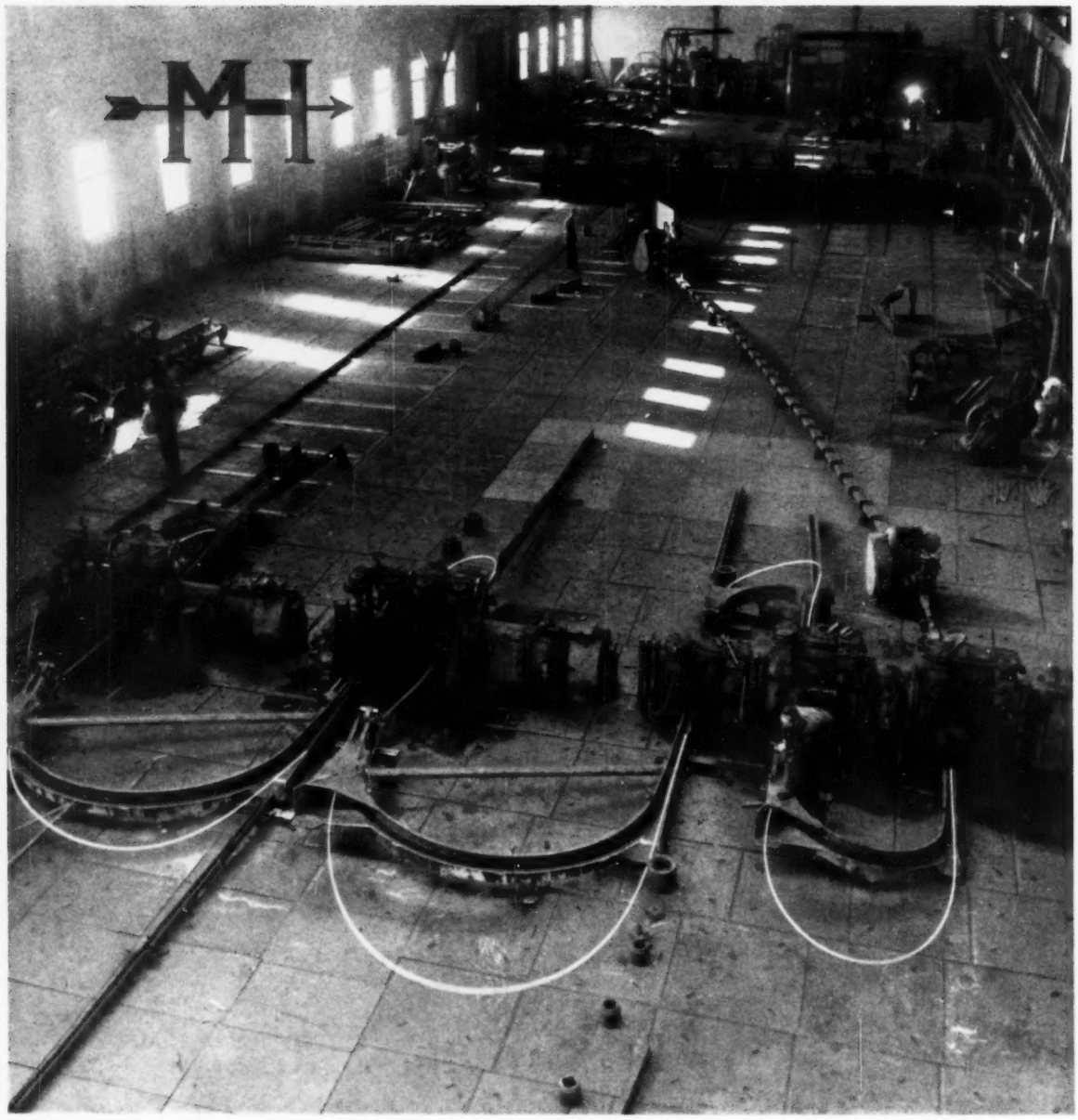

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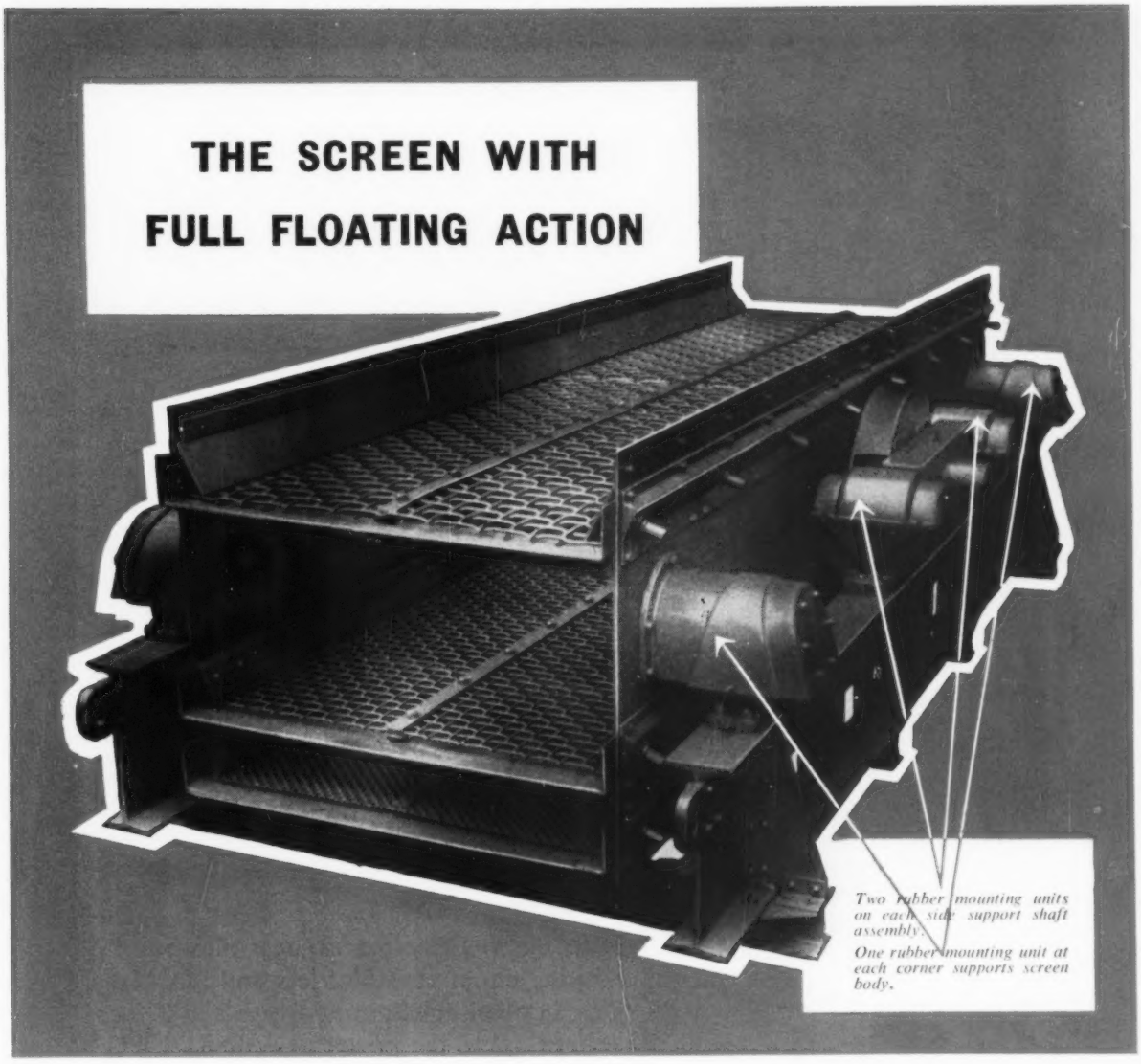
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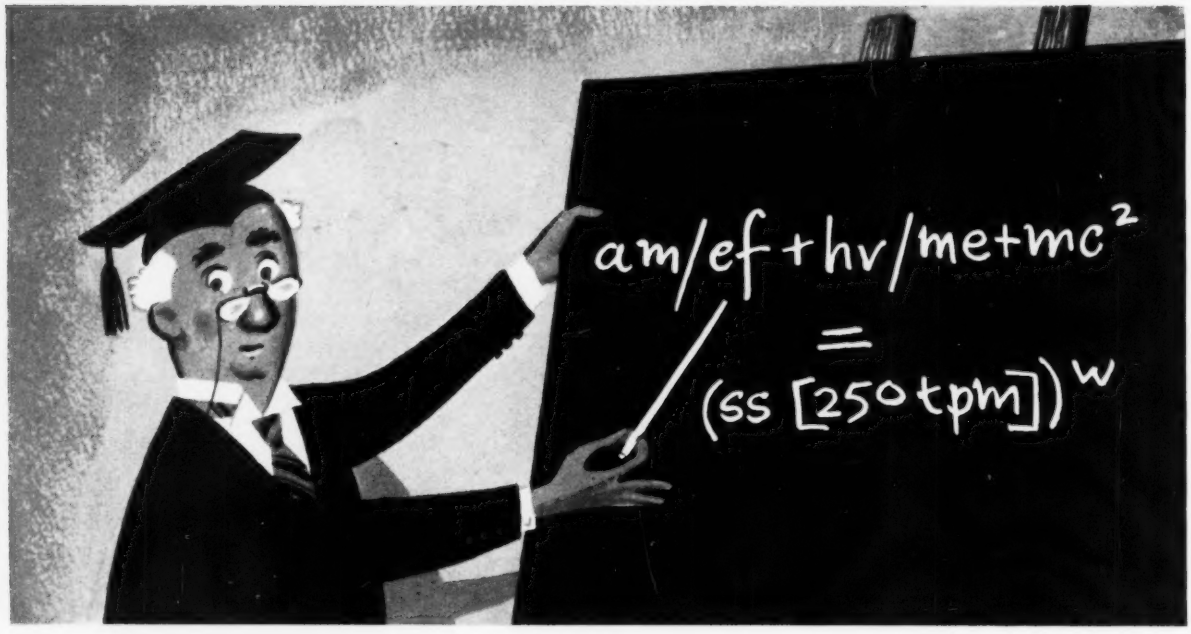

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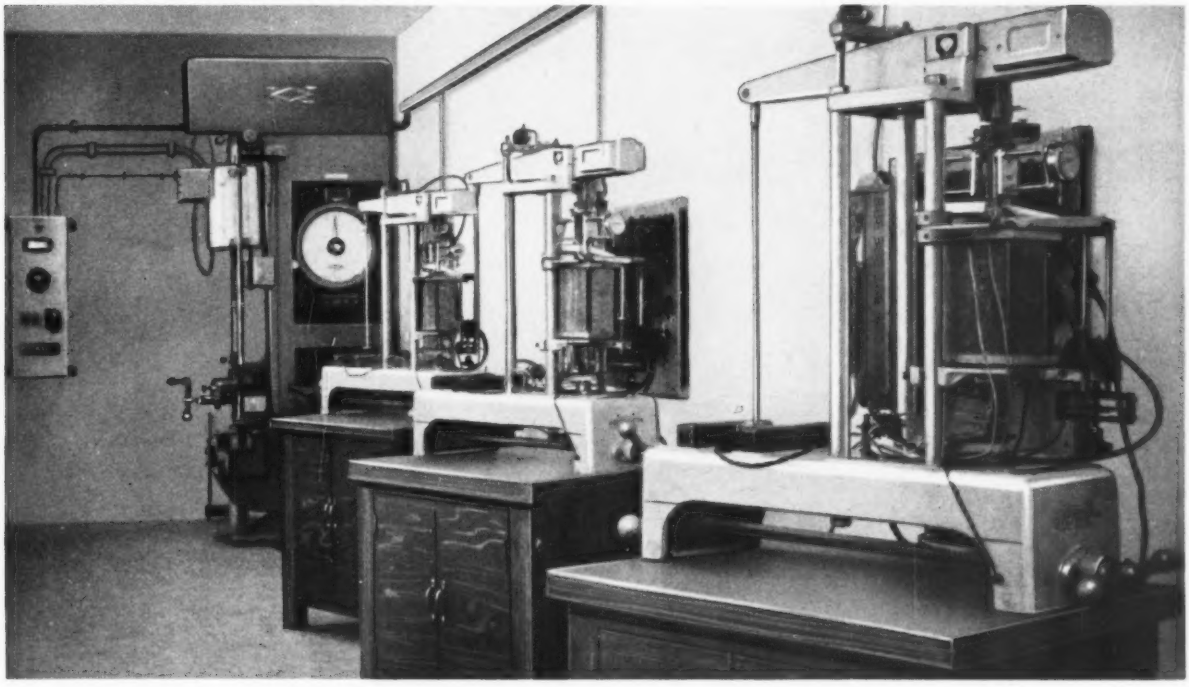

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The usual room-temperature tensile tests are not good enough for Thompson L'Hospied. They know exactly how each alloy behaves under load at whatever temperature it will ultimately be maintained in service. Test results from Stress-Creep and High Temperature Tensile machines are correlated to give absolutely accurate information which ensures perfection in both alloy and design. Thompson L'Hospied Heat resisting castings and Centrifugal castings do a fine job and stay on the job longer. Our advisory service — backed by long experience with the Furnace Industry — is freely at your disposal. Ask a representative to call.

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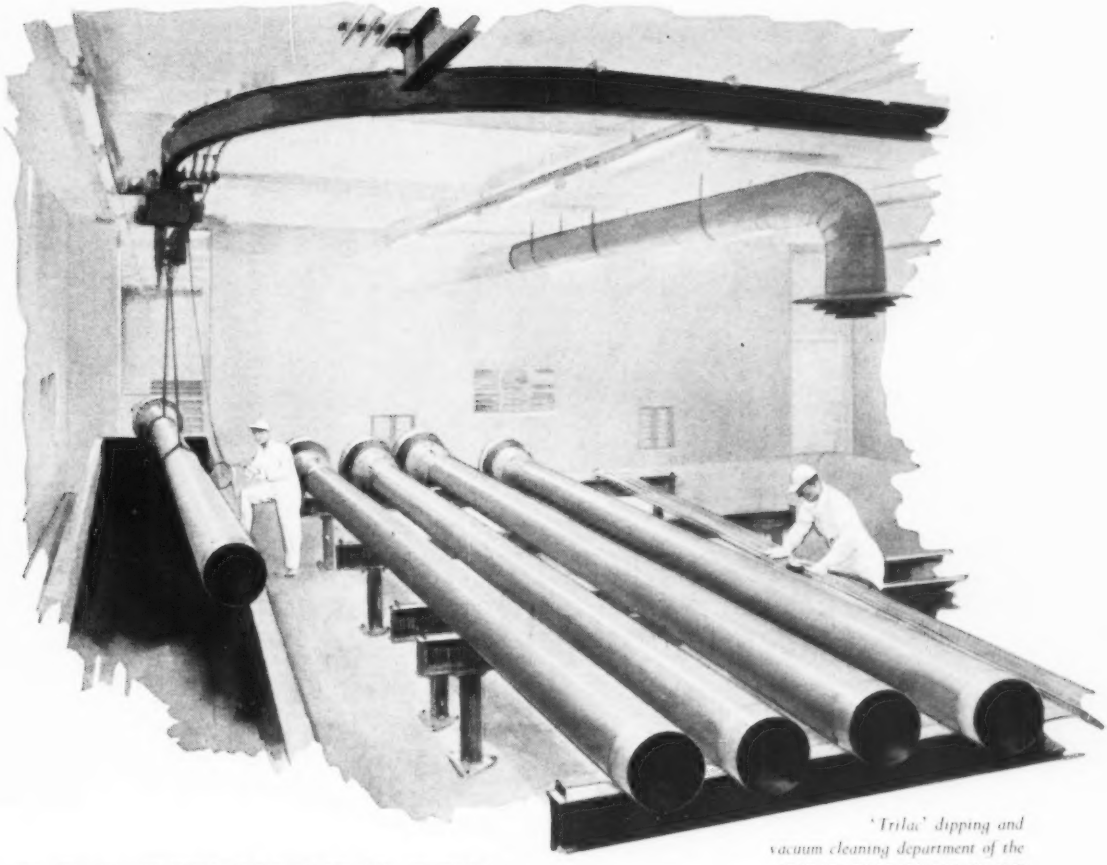

'Trilac' dipping and vacuum cleaning department of the 'CLEAN CONDITIONS' PLANT

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It is becoming general for many components for nuclear plants and other forms of construction to be assembled under entirely dust free conditions.

To meet the requirements of the nuclear age S & L have constructed a special 'clean conditions' plant at their Tollcross Works in Scotland. This new plant is probably the largest and best equipped in industry and comprises many important features, including fully filtered and heated air, a large assembly area, together with cleaning and protection facilities.

An example of the work assembled in this shop is the control rod standpipes for Hunterston nuclear power station. The standpipes shown in the illustrations accommodate boron rods and house the small bore burst slug detection piping.

S & L will be pleased to discuss any problems associated with clean conditioning of industrial components.

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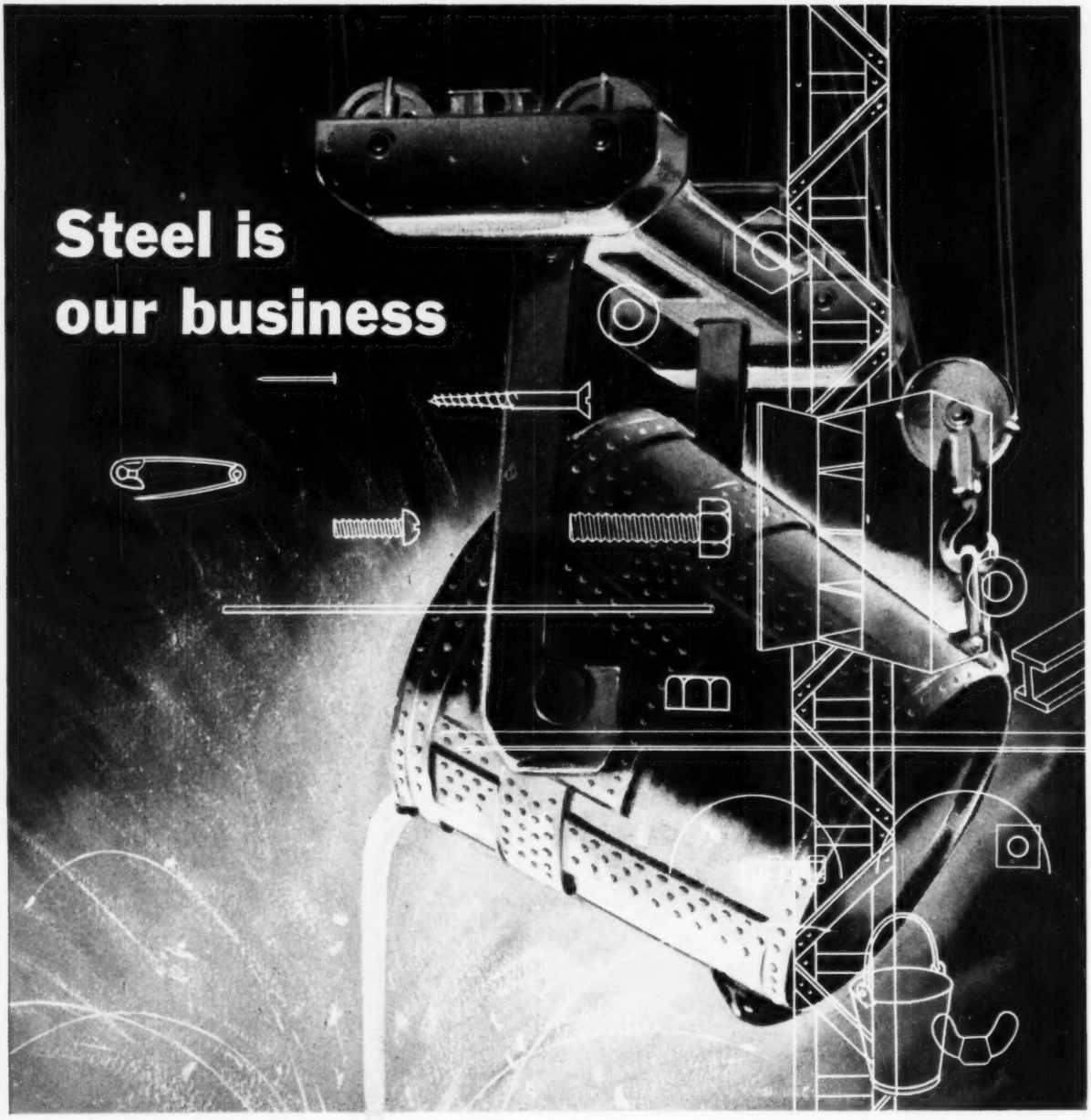

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Putting steel into shape in every conceivable form has long been the main activity among the companies in the GKN group. From safety pins to steel furniture, buckets to bridges, light pressings to giant stampings, the smallest screw to the largest steel buildings—GKN make something for every industry under the sun. Whatever is needed in the way of steel components or assemblies, there's a GKN company with the experience, the resources and the big-scale production facilities to supply it.

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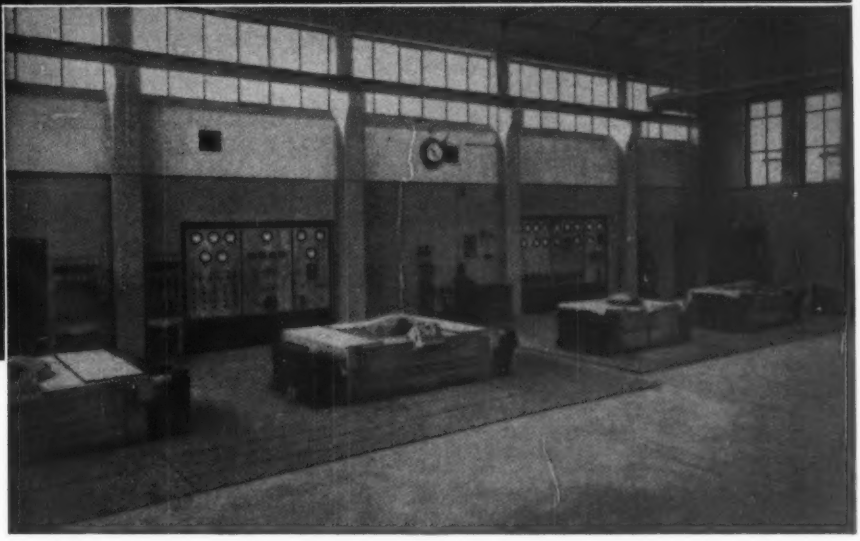
This GWB DEMAG alliance could mean a lot to you

There are problems associated with the induction melting of irons and steels which make it imperative for the intending purchaser of an induction furnace to consider all aspects of his production so as to obtain the most suitable furnace for his needs. Even for the same metal, the same furnace will not necessarily be the best type when consideration is given to charge characteristics and melting programme. Having access to the wide range of designs and long experience of Demag, G.W.B. are now in a position to offer the most suitable furnace to suit your own particular project. G.W.B. British built furnaces available for melting irons and steels include:

- **Crucible Type Furnaces for Mains Frequency or motor alternator operation.**
- **Channel Type Mains Frequency Furnaces.**

The electric induction method of melting irons or steels can solve your melting problems, and G.W.B. can help you in the choice of the correct induction furnace.



Demag High Frequency Induction Furnace installation for steel melting comprising two 1 Ton furnaces, two 6 cwt. furnaces and one 1 cwt. furnace.

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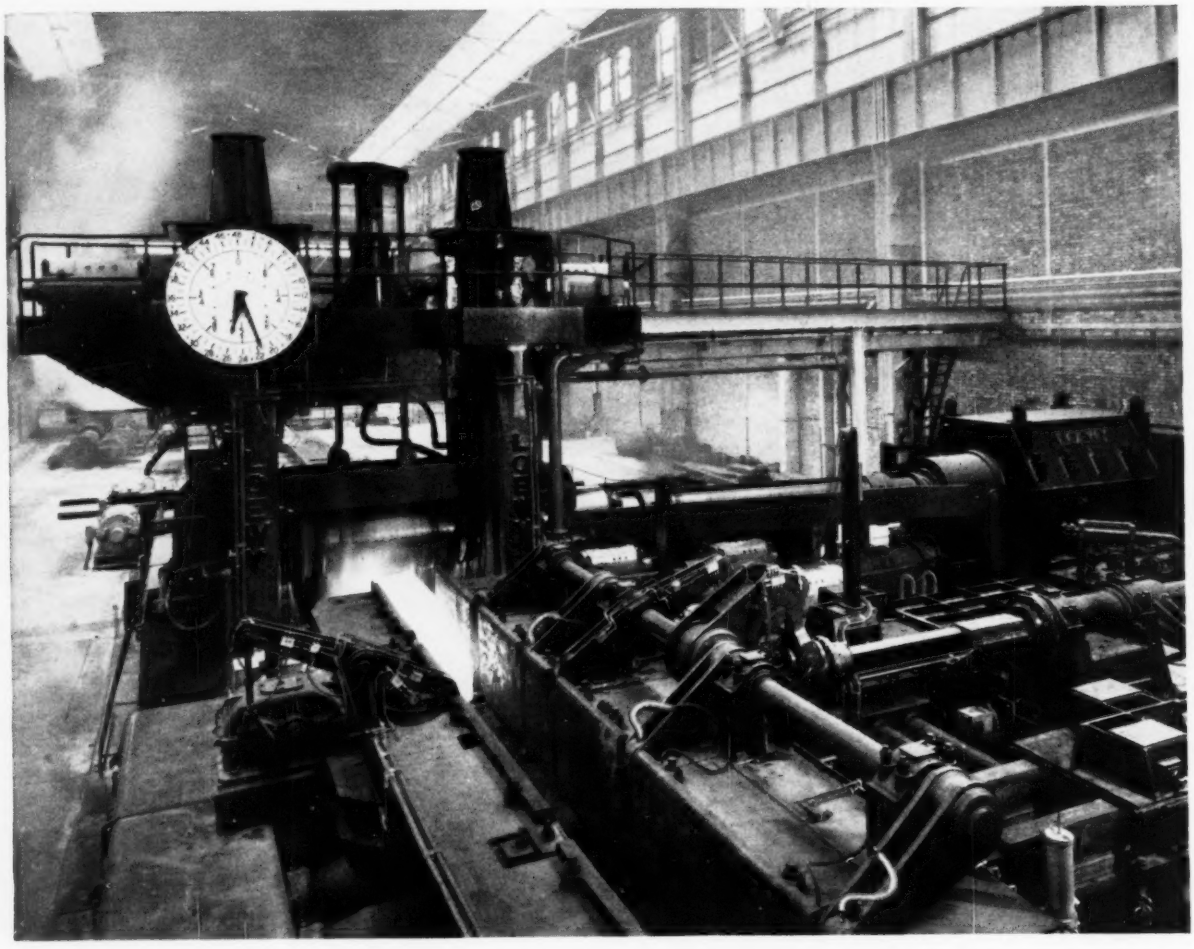

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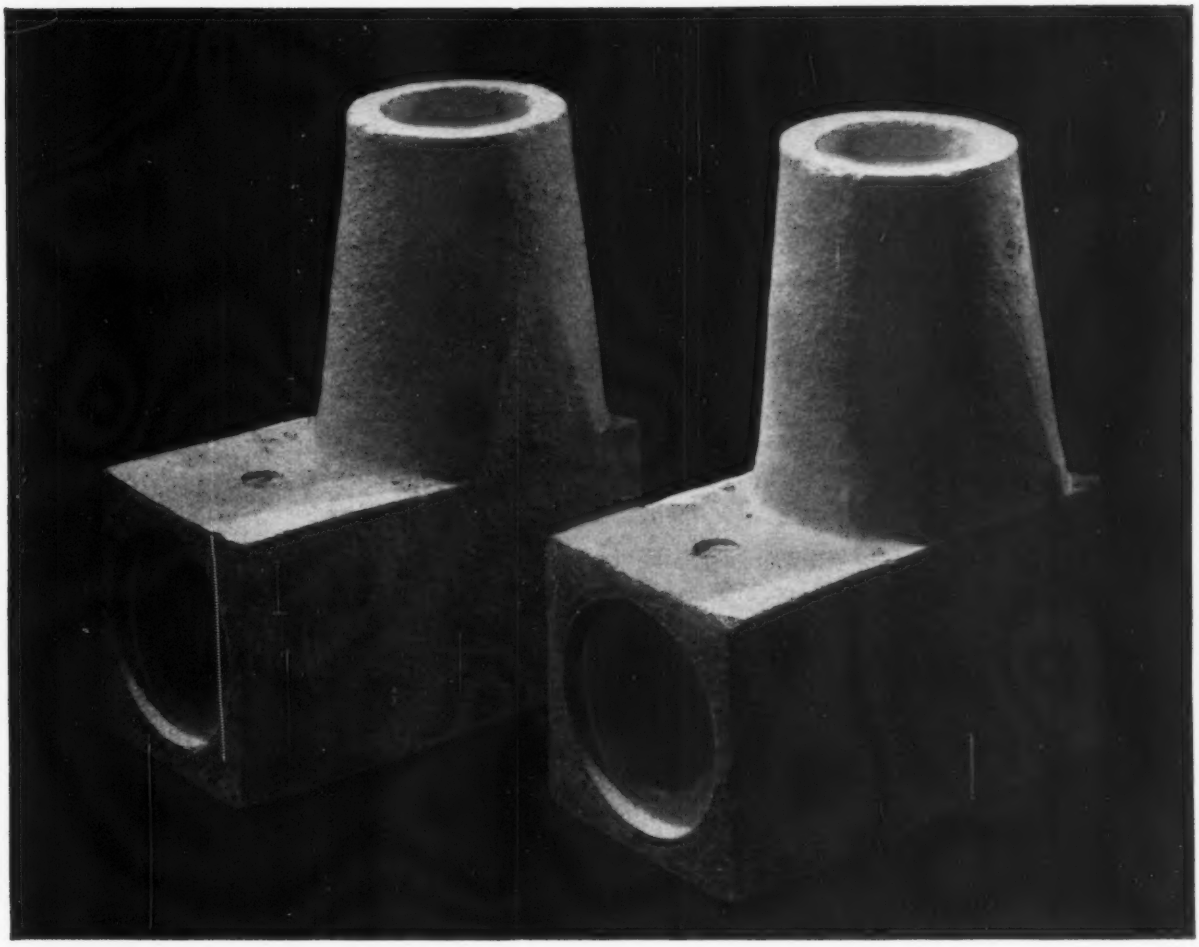

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Wraggs of Sheffield take justifiable pride in their end runner bricks as finished products. But they never forget that casting pit refractories are means to another end—that of producing clean, reliable steel for the world's great industries. That's why no refractories are allowed to leave Wraggs' works unless they are up to the highest standards of manufacture.

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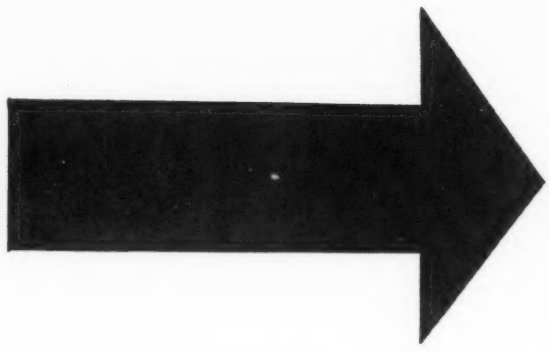
for reliable casting pit refractories

THOS. WRAGG & SONS (SHEFFIELD) LTD., LOXLEY, NR. SHEFFIELD. TELEPHONE: 343034

Steel's first 'Report to the Nation'

The British Iron and Steel Federation is adopting a new approach to the public in a series of advertisements in the national and provincial press entitled REPORT TO THE NATION. These advertisements, as they appear, will deal with current news of the steel industry. The first report is concerned, among other things, with the industry's production record and development plans; with some of the latest uses of steel; and with the social conditions of workers in a typical steel producing area. Future reports will explore other sides of the industry : the personalities running it; research activities; management training.

The first report has already appeared. It will be followed by others at intervals during the year, and almost everyone in the country will have a chance to see them. In this way, people can learn not only how a vital industry operates, but also how closely the prosperity and everyday life of the nation is bound up with that of Steel. The Reports will be important, too, in helping those within Steel to know it better, and to realise they're part of an efficient, progressive and booming industry.



STEEL – NEW YL... TO THE N...

HOW MUCH STEEL IN 1960?

THE British steel industry may well produce about 24 million tons of steel in 1960 – compared with 20 million tons last year.

Last year, and the year before, the steel industry spent some £100,000,000 on new plant and development – and raised its production capacity by about a *million* tons each year. This was done despite the fact that existing capacity, except in a few cases, was not being fully used.

Why this expansion, then? Is it an act of folly – or farsightedness? It is simply an expression of confidence in Britain's future.

Apart from the sharp set-back around 1958, when the industry was working far below capacity, demand for steel has shown a steady upsurge since the war. Looking forwards, the industry has weighed forecasts made by its customers about their future demand.

As a result the industry believes that the trend of steel demand will continue to rise.

Planning ahead in Steel is a ticklish business. It means foreseeing future developments in the economic life of the nation, and the changing needs of steel consumers.

Among the thousands of steel-using firms the pattern of demand can change almost overnight. But planning, building and bringing into production a new steelworks inevitably takes years.

UNEXPECTED

A plant making rails cannot change over to production of sheet for cars.

Hence in the past two years, although the steel industry as a whole has not been working at full capacity, there have sometimes been shortages of steel sheet.

Why? The causes were an unexpectedly swift boom in cars – which took even the motor industry itself by surprise; rising sales of household goods like cookers and washing machines, and of electrical machinery; and a shift in demand from one kind of steel sheet to another.

£760 MILLION

Not even the wisest brains can predict, years ahead, every future shift in the pattern of demand. But Britain's steel industry has done remarkably well since the war in having the right plant ready at the right time.

Since the end of 1946, a sum of over £760,000,000 has been spent on development. The graphs show the crescendo of expansion in the last seven years; and also how the steel industry, far from lagging, has gone ahead faster than other manufacturing industries.

NEW MILLS

In the critical field of cold reduced sheet, production in 1959 was 13% up on 1958, and will rise again by perhaps as much as 20% in 1960. Further expansion at existing strip mills and construction of two new mills at Newport and Ravenscraig, work on which is being accelerated, will meet the likely demand for sheet and tinplate.

What of the other sections of the industry? Although hit by the recession, they have pressed on with expansion. The new Universal Beam Mill at Lackenby, best of its kind in the world, is in production – indeed, everywhere the nationwide programme of steel development is accelerating. At the lowest point (December, 1958) the industry was operating, on average, at about 70% of capacity. Now the rate is over 90% – of a greater capacity.

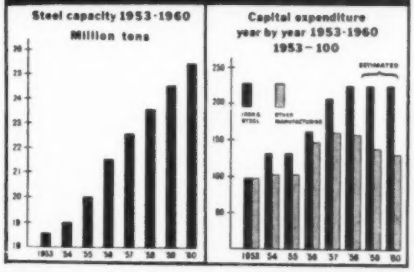
UP AND UP

Prospects are that there will still be some margin of capacity in 1960 in certain heavy steel products, as a result of continued slackness of demand from railways, coal mines, and shipbuilders. But demand for other types of steel is expected to rise still further.

Steel production in 1960 may therefore be between three and four million tons more than in 1959.

Continued modernisation and expansion – at a cost of over £100 million a year – will provide an efficient steel capacity of over 30 million tons by 1965, a sound basis for competing in world markets.

SEVEN YEARS OF STEADY PROGRESS



SIXTY KINDS OF STEEL ON T...

Steel takes these shock

THEY do brutal things to a car, down at Nuneaton, on the proving grounds of the Motor Industry Research Association. And every time they test a car, sixty different kinds of steel are on trial. That's how many there are in a modern car.

One of the tortures have devised consist pavé track made of stone blocks, set angles, with pier pot-holes. They li drive cars across it.

And what bears brunt of this savage

Fifty

New life in the Valleys

BY TREVOR EVANS

THE "black years" of the twenties and thirties are not yet forgotten in South Wales. So it was with deep misgivings that I went back to the village where I grew up.

I was never so surprised in my life. I rubbed my eyes, thinking for a moment that I had driven into the wr...

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This illustration shows the grinding of a double cone following the special heat treatment of the machined high-nickel-alloy steel forging. Part of this bearing is shown half-size in blue; it is 52½ ins. outside diameter, 37 ins. bore and 37½ ins. wide.

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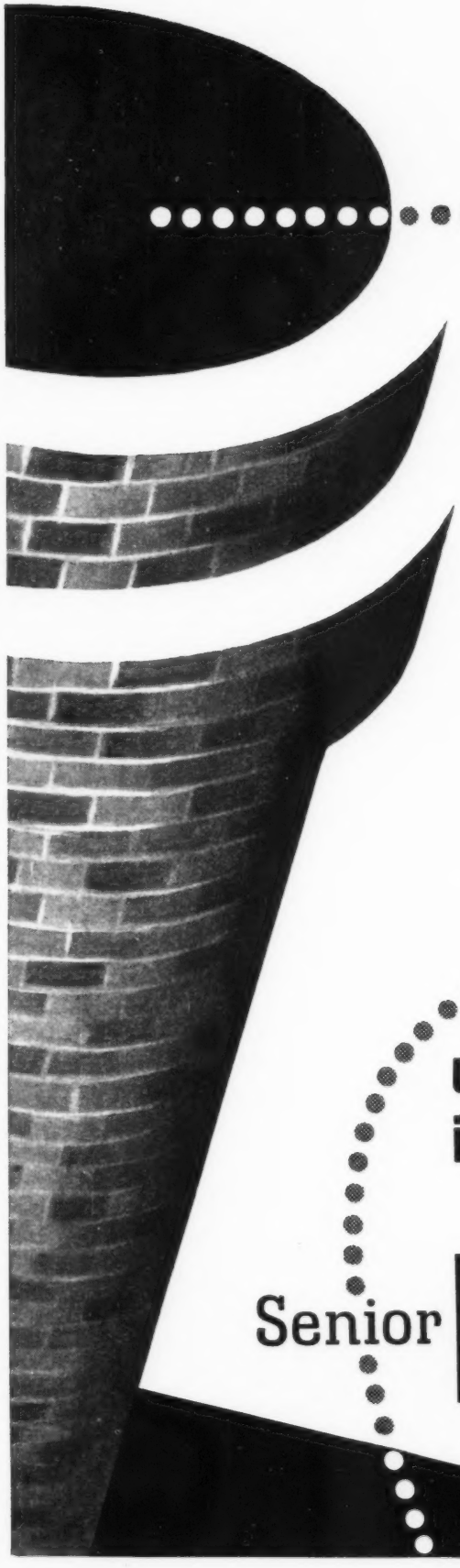

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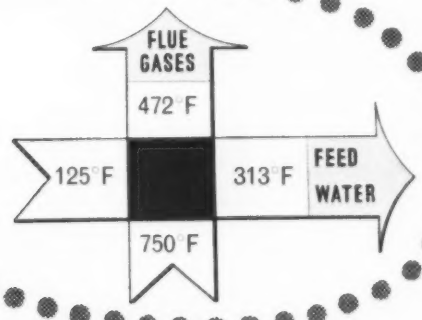
Diagram shows temperature figures in a typical installation.



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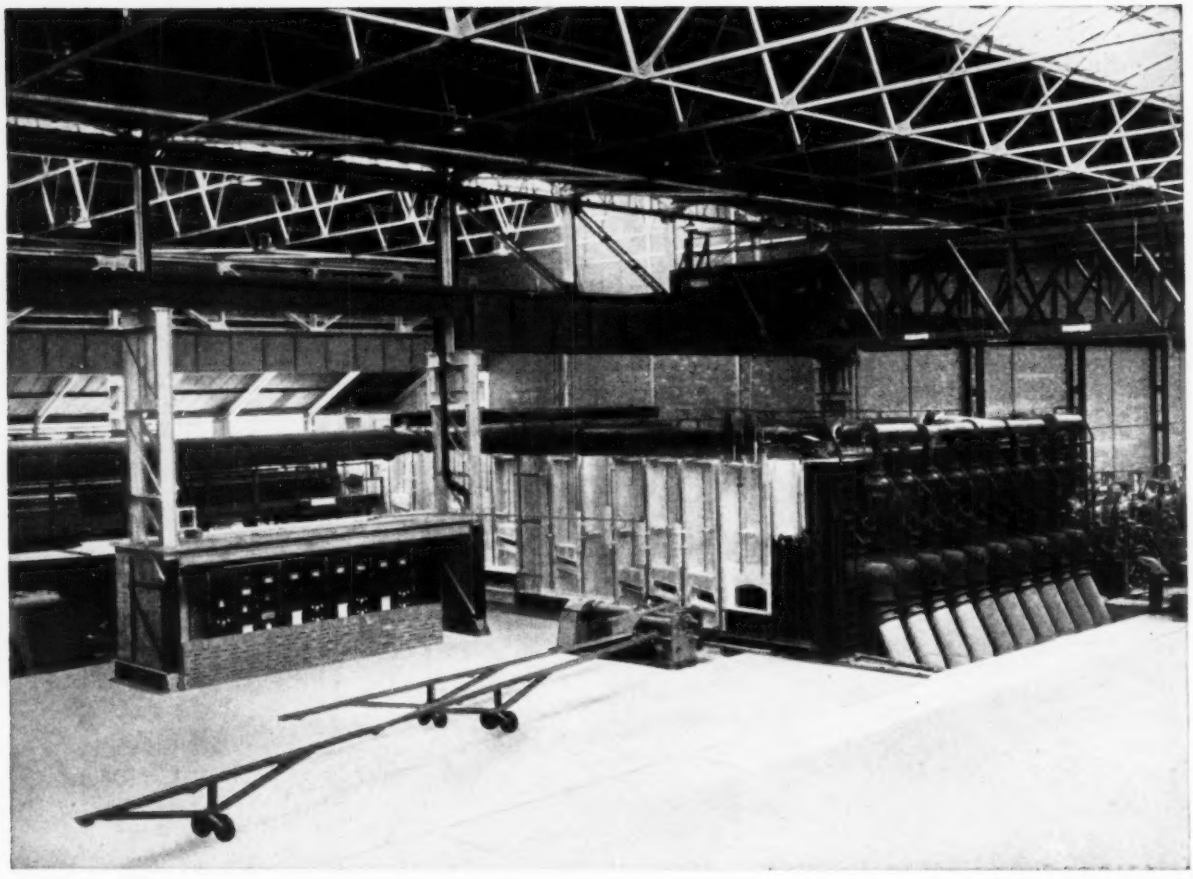

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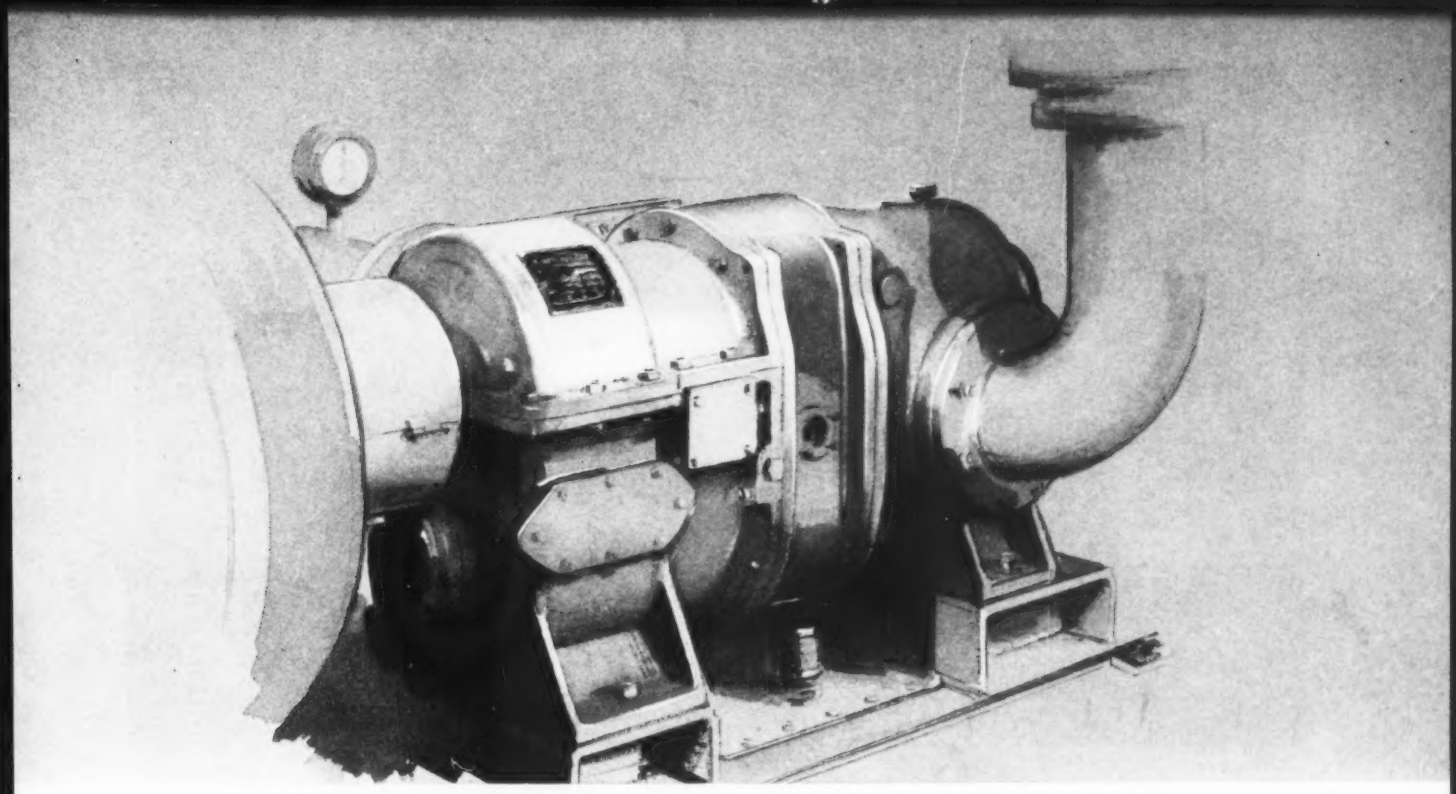

Howden rotary-screw compressor, 1100 c.f.m., exhausting at 1/5 of an atmosphere at the AIRCRAFT RESEARCH ASSOCIATION, BEDFORD

Howden Compressors

For more than 12 years, Howden have been manufacturing and developing rotary-screw compressors. Howden compressors have many outstanding advantages, as follows:—

As rotary-screw compressors without any reciprocating parts they are fundamentally free from out-of-balance forces, with a large output in relation to their size. With their high speed and freedom from valves they give a pulseless delivery.

Accurate gearing maintains the rotors with a designed clearance; thus they never touch and are less affected by air-borne impurities. The rotors need no lubricant; the air or gas delivered is therefore oil-free, an advantage in certain industries and an economy in all.

Howden compressors are driven through Howden speed-increasing gearboxes from any suitable power source.

ECONOMICS OF THE COMPRESSOR

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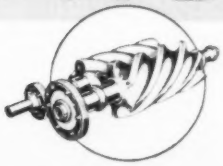

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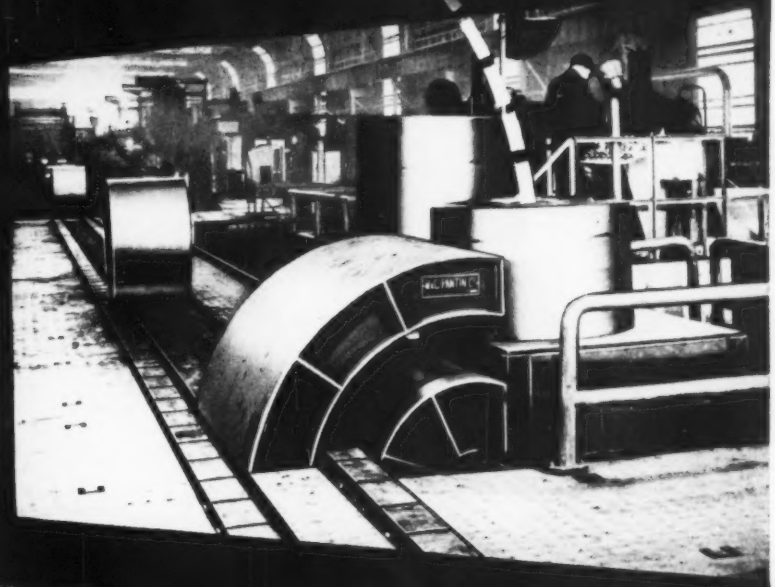
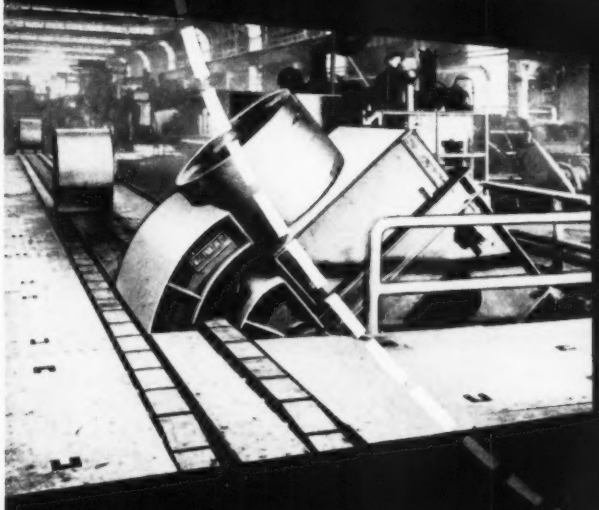
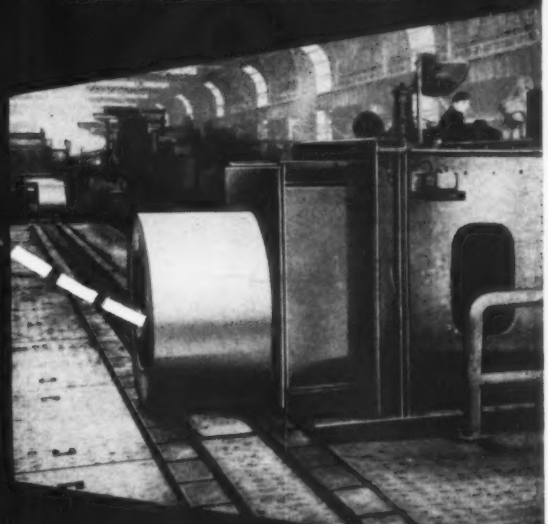




Pantin design and manufacture heavy duty mechanical handling plant for the Iron and Steel Industry.

This 'Upender', for example, was made to simplify and expedite the handling of coiled steel. With the utmost ease it takes coils up to 15 tons (max. dimensions 6' diam. × 6' wide) and lays them on a Pantin Pallet Conveyor for movement to the next station.



Pantin Handling Equipment covers every requirement, including upending and down-ending, tilting, hoisting and conveying of coils and sheets.

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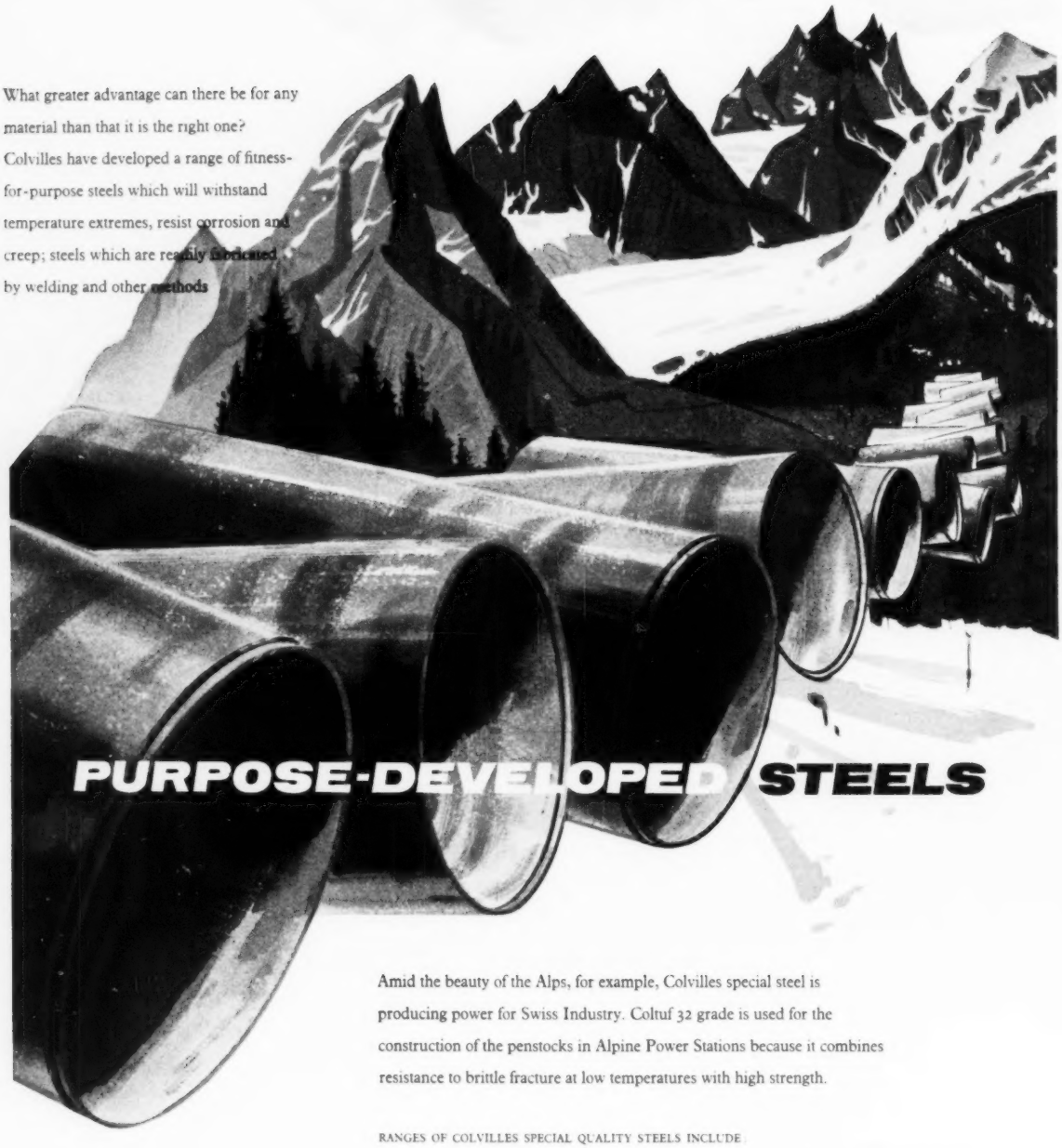

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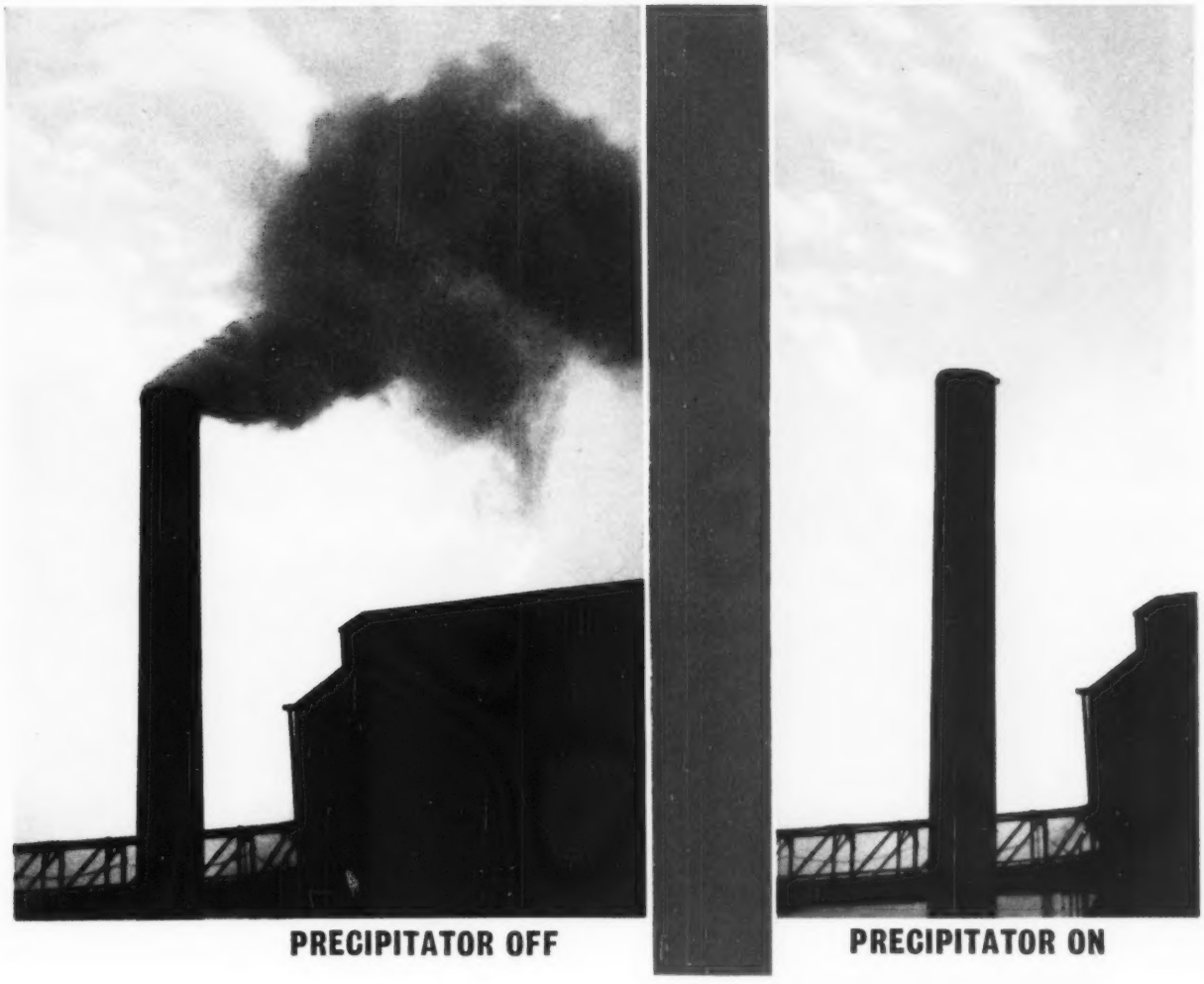

PRECIPITATOR OFF **PRECIPITATOR ON**

The photographs reproduced above were each taken at the moment of peak fume production from the scarfing process on two successive cycles of operation. They give a clear indication of the efficiency of the Holmes-Elex Electrical Precipitator which is cleaning exhaust air from the deseaming plant at the Rotherham Works of Messrs. Steel Peech & Tozer (Branch of the United Steel Companies Limited).

The first electrical precipitator to operate on deseaming plant in the United Kingdom was installed by our Gas Cleaning Division at the Corby Works of Messrs. Stewarts & Lloyds Limited in 1954. A further installation was recently commissioned at the Bilston Works of the same company.

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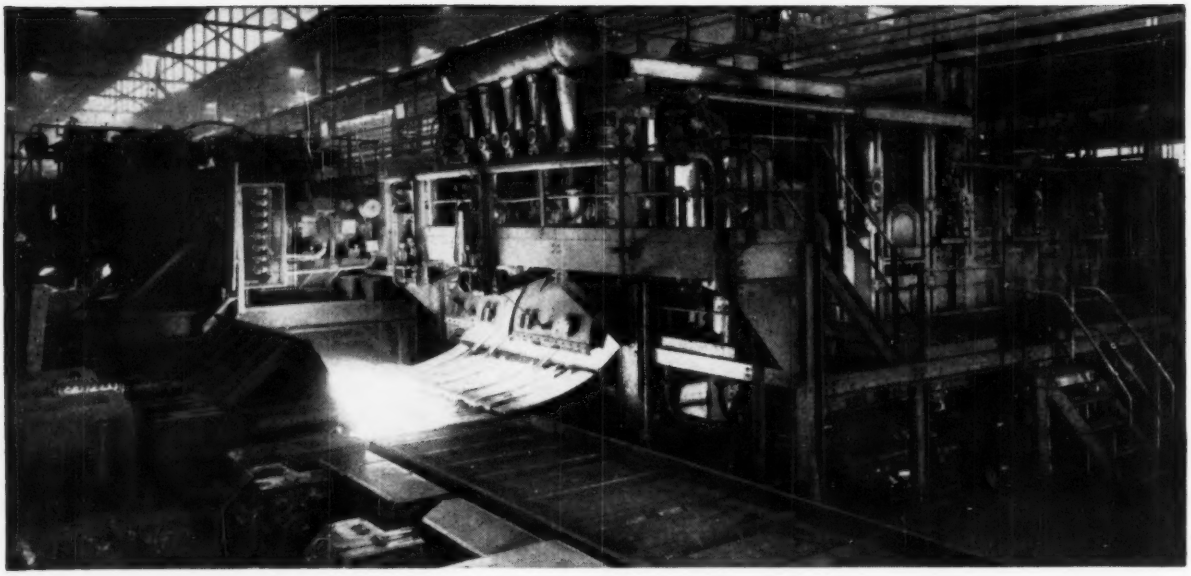

Fig. 1. A hot slab being ejected from the furnace on to the roller table.

THE GLAMOUR OF STAINLESS STEEL

Stainless Steel—a British discovery by Brearley in Sheffield in 1913, overcame the atavistic tendency of ordinary steels to return to iron oxide as rust.

Now highly polished Stainless Steel adds glamour to kitchens and hotel, office and shop fittings. Perhaps more important, its resistance to corrosion offers a hygienic surface to the food manufacturing industries, large scale caterers and for hospital equipment, including sterilisers and the surgeon's delicate instruments.

This glamour applies not only to Stainless Steel products, some of which are illustrated in this article, but also to its processing. In fact, the ultimate durability of Stainless Steel depends upon a precise temperature time heating and reheating schedule, which processes are usually carried out by town gas because of its inherent flexibility as a heating medium.

Fig. 1 shows a close-up view of a slab heating furnace at Shepcote Lane Rolling Mills Limited—a subsidiary company of Firth-Vickers Stainless Steels Limited, in which Samuel Fox & Co. Limited have a one-third interest. In the illustration a red hot slab has just been ejected on to the run-out table. This furnace heats nine tons of slab hourly at a temperature of 1,230°C before ejection, using 35,000 cubic feet of town gas per hour—each slab weighing approximately three tons.

The impressive machinery used to process Stainless Steel is shown in Fig. 2—the plant producing either matt or mirror-finished coiled strip. In the background are shown the gas-fired slab-heating furnace and the primary rolling section. The gas-fired coil reheating furnaces and the automatically controlled four-high finishing mill together with the run-out table are shown in the foreground.

Fig. 2. A general view of the hot mill bay showing furnaces, Steckel Mill and run-out table.

Fig. 3. The four-high hot Steckel Mill installed at Shepcote Lane Rolling Mills Limited.

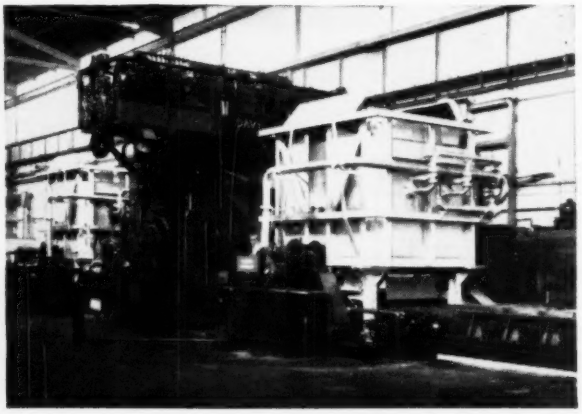

Fig. 3 shows the complex four-high Steckel Mill with its adjacent coil reheating furnaces. Each furnace is rated at 8,000 cubic feet per hour, and the plant will roll up to nine passes with a drop in temperature of the steel of only 250°C.

The treatment of Stainless Steel is only one of thousands of different trades, professions and processes served by the Gas Industry. Each Area Gas Board has specialist staff familiar with the heating problems of these many industries. They all pool their ever-increasing knowledge through the Gas Council's Industrial Gas Development Committee, whilst the Industrial Gas Information Bureau keeps in touch with developments in gas-fired equipment in all parts of the world. Thus any user, or potential user, of gas-fired equipment has a fund of technical knowledge available to him by asking for the services of his Area Gas Board.

Fig. 5. Receiving and storage tanks for margarine blends in the processing department of Van Den Berghs & Jurgens Ltd., Stork Margarine Works, Purfleet.

Fig. 4. A sterilising unit for surgical and dental instruments.

Fig. 6. The Wimpy, Lyon's Corner House, Coventry Street, London.

Fig. 7. The largest stainless steel carpet dyeing machine ever produced in Great Britain.

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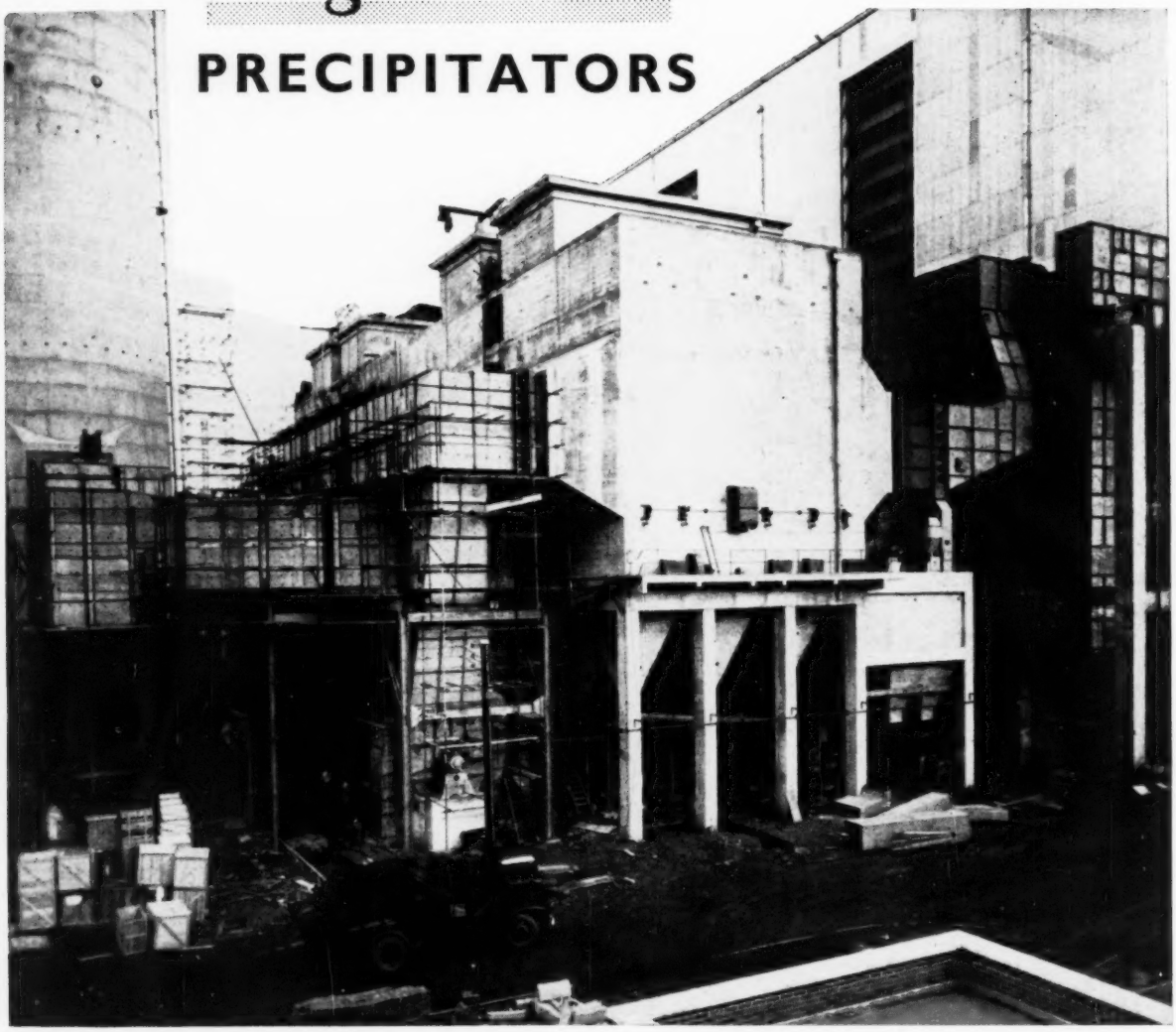

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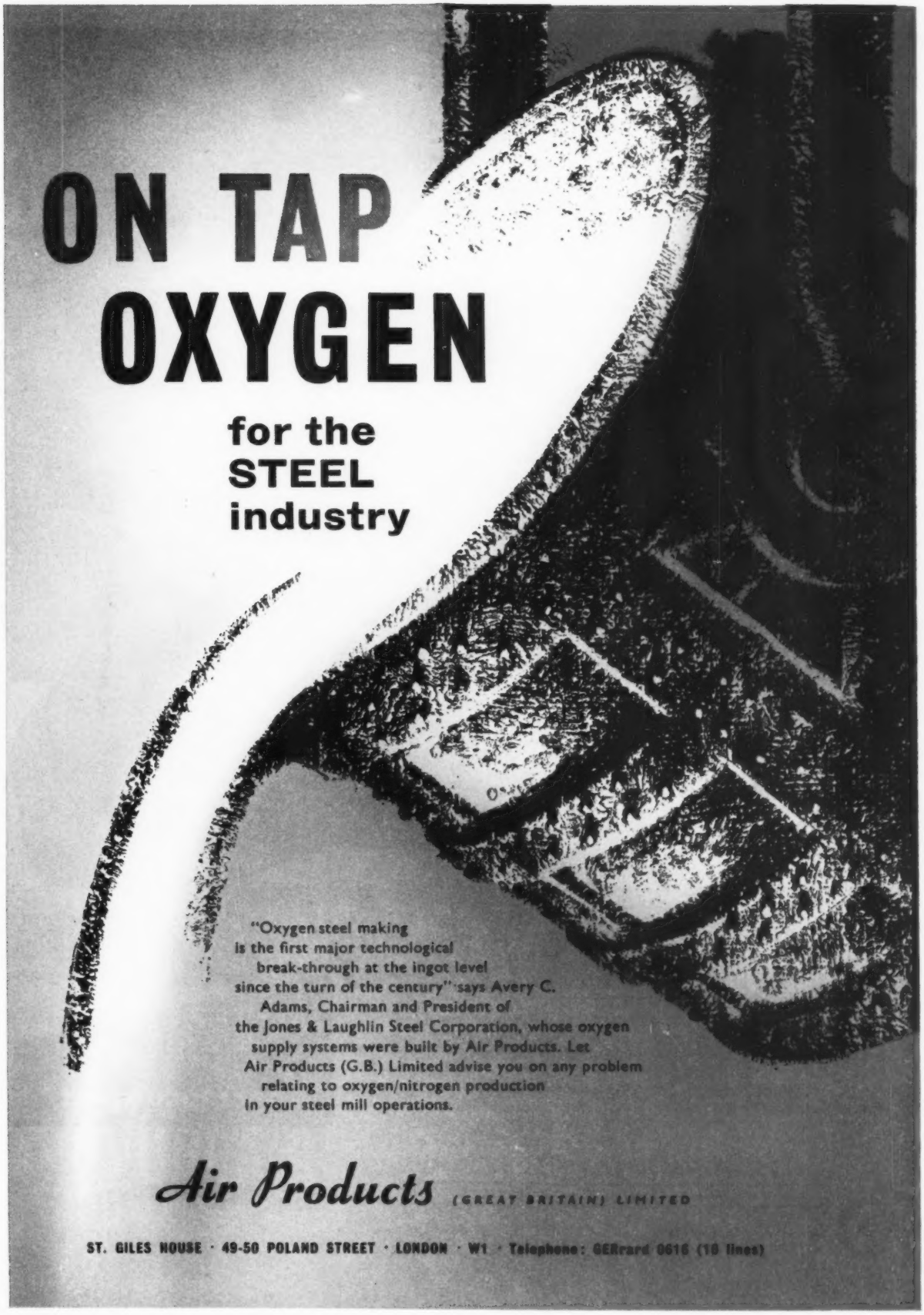

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Robertson's machines, which are in operation throughout the world, help man to work metals ever faster, ever better and ever more accurately.

Photograph by courtesy of The Steel Company of Wales Ltd.

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ROLLING MILLS

Robertsons manufacture a wide range of equipment for steel mills, and the illustration depicts a 32" × 80" two-high Sheet Skin Pass Mill installed in the Abbey Works of the Steel Company of Wales Limited.

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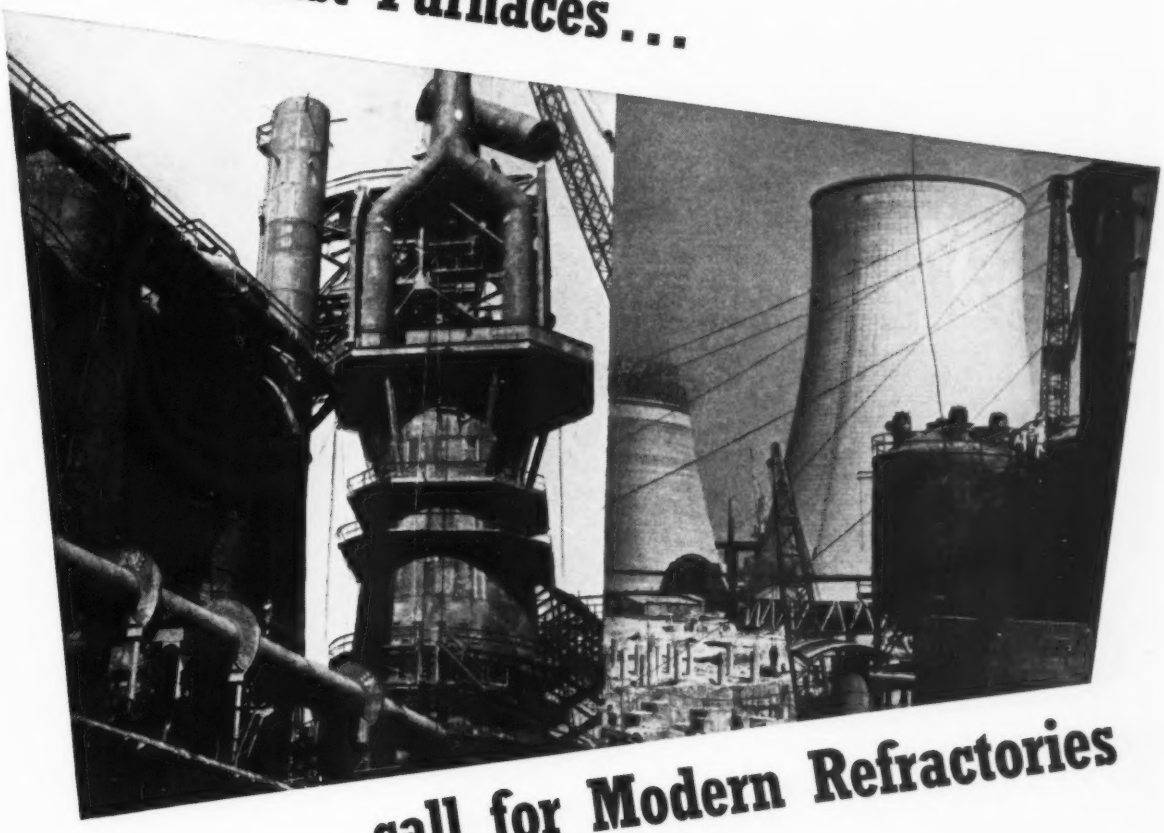

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FOSTER HIGH GRADE

For use in lower chequers, main stove side walls.

' Foster ' is one of the great names in Blast Furnace refractories and Foster refractories (as listed) make an important contribution to the new ' GR ' range of Blast Furnace refractories. This range offers users the widest available choice of new and improved products with which to combat the severe conditions of modern furnace operation. This outstanding advance is yet another example of ' GR ' research, enterprise and practical knowledge in action, one more of so many refractory developments which this organisation places at the command of the world's iron and steel industry for even greater efficient and economical production.

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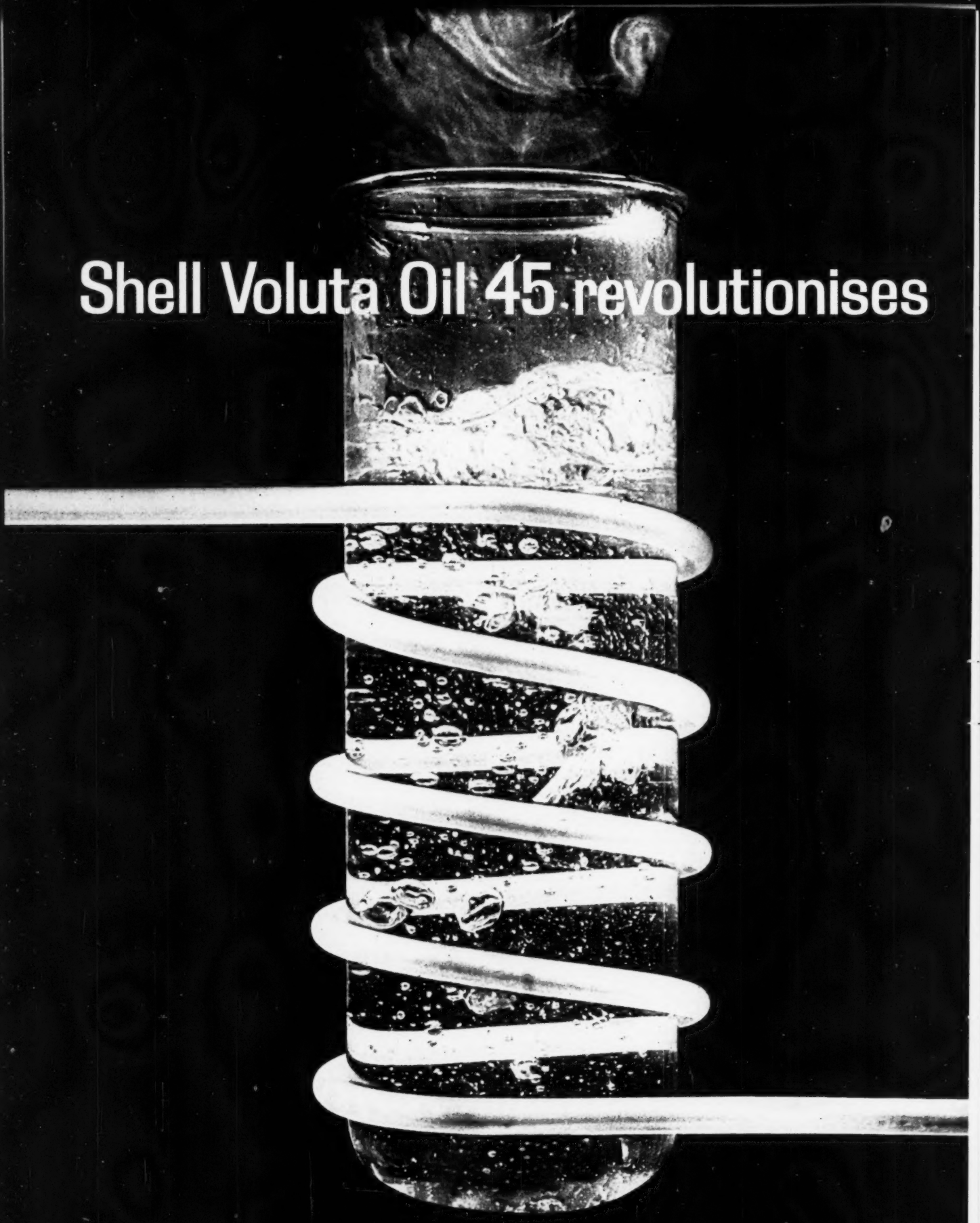
Shell Voluta Oil 45 revolutionises



heat exchange practice

Before Shell produced Voluta Oil 45 it was thought that oils which were to be used for heat exchange purposes must have a high flashpoint —to reduce fire risk, and a high viscosity—to prevent excessive leakage through pump glands and to provide adequate lubrication for pump bearings at high temperatures. Heat exchange systems containing these viscous oils, however, were sluggish, particularly when started up from cold. The oil circulated slowly over the source of heat and suffered thermal decomposition, or "cracking". This, in turn, produced low flashpoint materials and carbon which insulated the heating surface.

Shell, therefore, began investigating the suitability of oils of lower viscosity and different chemical constitution. From this research was developed Shell Voluta 45.

Shell Voluta 45 contains hydrocarbons with a saturated ring structure which does not have the tendency that high viscosity straight chain paraffin hydrocarbons had—to break down at high temperatures. Because of its low viscosity Shell Voluta 45 heats up more quickly from cold and circulates more rapidly thus avoiding local overheating and thermal decomposition.

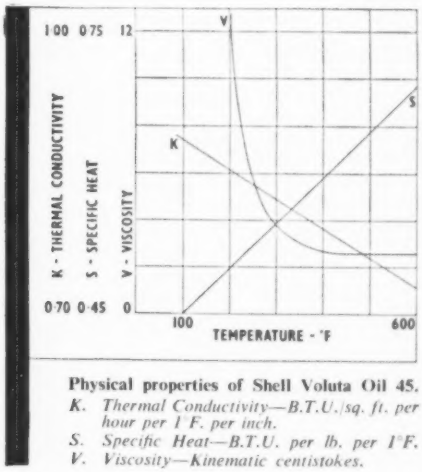
Shell Voluta Oil 45 has excellent heat transfer properties, good thermal stability and good lubricating properties. It is recommended for use in all closed heat transfer systems.

The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Laboratory research to compare the high temperature performance of various oils in a rig simulating practical conditions showed that when oils of varying viscosities were maintained at an average temperature of 325°C. for 200 hours, the closed flashpoint of the high viscosity oils had dropped to a lower figure than that of oils of lower viscosity, indicating that some thermal decomposition had taken place.

Experimental oils were subjected to Heat Stability Tests and to tests designed to measure the variation in heat transfer coefficient with time. The most promising of these oils was then given extensive field trials, both in Shell Installations and in industry. From this extensive research was developed Shell Voluta 45.



Physical properties of Shell Voluta Oil 45.
K. Thermal Conductivity—B.T.U./sq. ft. per hour per 1°F. per inch.
S. Specific Heat—B.T.U. per lb. per 1°F.
V. Viscosity—Kinematic centistokes.

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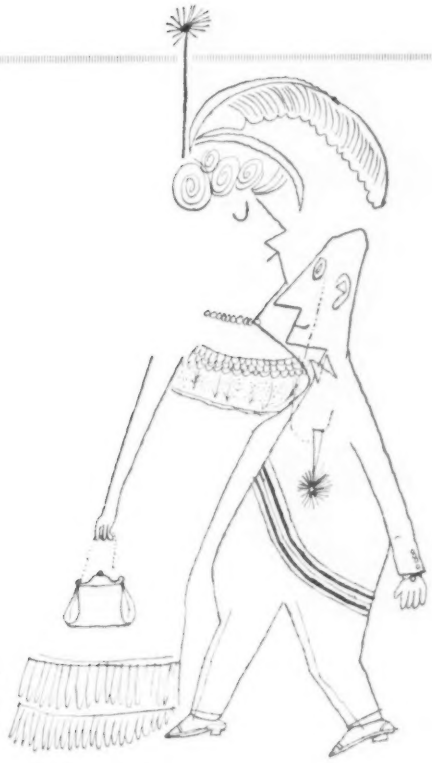

Rarely are the contours of dancing partners quite so happily disposed. In such a

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case indifferent navigation is a small price to pay for the convenient accommodation of peak and bluff, outcrop and escarpment ● Here, in the City of Steel, we make sheet steel that follows as closely its intended purpose. Each order is a separate assignment and our sole concern is to see that your product gets the particular kind of steel it needs ● Steel, in fact, made to measure — to your exact requirements.

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CHARACTERISTICS OF HOLSET COUPLINGS

- Can accommodate substantial angular and parallel misalignment.
- Absorb shocks and operate noiselessly under any conditions.
- With a multi-row arrangement of the blocks, Holset Flexible Couplings can have a small diameter and, therefore, a lower WR^2 value than any other torsionally resilient coupling.
- Do not create any end thrust on the bearings of the connected shafts.
- Provide electrical insulation between the driving and driven machines as there is no metal to metal contact.
- Do not require lubrication or maintenance of any kind.
- Installation of Holset Flexible Couplings is simplicity itself. As there are no spigots, removal of the bolts permits vertical lift of the driving and driven machines.
- The design is consistent throughout the range of standard sizes which extends to couplings with a torque capacity of 400 metre tons.

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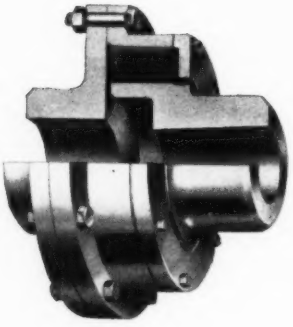

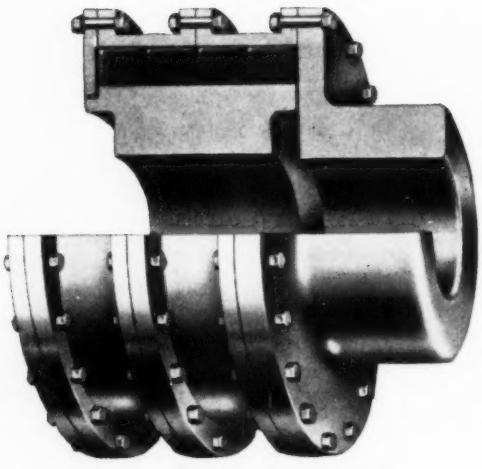

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This installation for the Tunnel Portland Cement Company, involved the manufacturing and laying of rail and crane tracks along the new jetty and joining up to existing tracks on the old jetty. The tracks are 75 lb. F.B.B.S. 'R' and 98 lb. F.B.B. Railways section.

The combination joining the new and old jetties to the main access tracks, is a treble junction and Goliath crane track comprising three turnouts, three diamond crossings and thirteen crane crossings, all prefabricated and laid down as a unit at our Works to ensure the minimum disruption to traffic. In addition, six throughroads were manufactured and installed as well as 1,053 yards of straight and curved crane and rail track, most of the crane track angle guarded.

This is yet another example of Summerson's resources and 120 years experience in the design, manufacture and laying of railway sidings.

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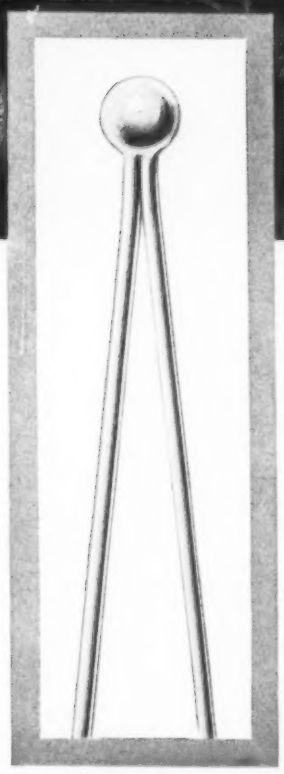
Spectacular...but



. . . but dependent so much upon the unspectacular — the platinum:rhodium-platinum thermocouple, which plays a vital role in all high-temperature processes where accurate measurement is essential to exact control.

Simple, robust, consistent, the thermocouple is to both industry and research a means without equal of precise high-temperature determination.

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I.91

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Choose your equipment from this new comprehensive range

Kelvin Hughes ultrasonic flaw detection instruments and probes are available for all-manual, semi-automatic and automatic testing techniques. High performance and versatility are obtainable with this comprehensive range of competitively-priced equipment, designed for laboratory work as well as routine inspection schedules. Auxiliary units include Automatic Flaw Alarms, Depth Gauges, Probe Holders and Manipulators.

TWO-CHANNEL FLAW ALARM

This portable auxiliary unit, designed specifically for use with KELVIN HUGHES Flaw Detectors, provides automatic monitoring facilities which hitherto were obtainable only with larger, more expensive equipment. Significant defects are identified automatically and are indicated by warning lights and alarm devices.

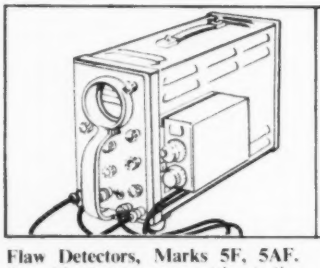
PRINCIPAL ADVANTAGES:

• Removes the onus of signal discrimination from the operator • Reduces operator fatigue • Reduces inspection time • Reduces inspection costs

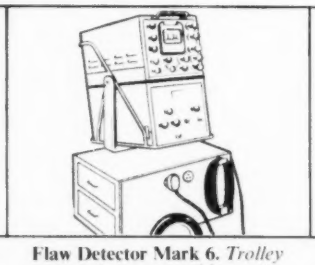
TECHNICAL FACILITIES:

• Simultaneous examination of two independent regions in the material • Automatic indication of the presence of flaws within these regions • Independent adjustment of the depth of each region under inspection • Independent adjustment of the position of each region • Independent adjustment of the sensitivity within each region.

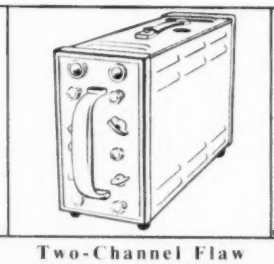
The Flaw Alarm Unit weighs only 20 lb. (9.1 kg.) and the Flaw Detector only 28 lb. (12.7 kg.), thus a completely semi-automatic inspection equipment, which can easily be carried by a single operator, is now available.



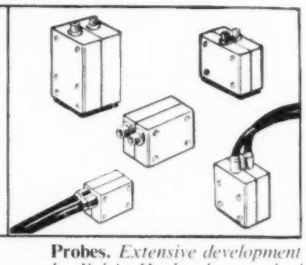
Flaw Detectors, Marks 5F, 5AF. *Portable instruments with similar basic specifications. The 5F is a multi-frequency instrument for use with twin or separate type probes, whilst the 5AF, a single frequency instrument, either 1½, 2½ or 5 Mc/s. Also operates with single type probes. (Shown with Depth Gauge attachment).*



Flaw Detector Mark 6. *Trolley mounted transportable equipment, very powerful and versatile for use with all types of probes and having an exceptionally wide frequency range and high sensitivity.*



Two-Channel Flaw Alarm. *For use with Mark 5 instruments, a portable auxiliary unit providing semi-automatic monitoring facilities which identify and give warning of significant defects.*



Probes. *Extensive development by Kelvin Hughes has resulted in a range of standard probes having either single, twin or separate transducers, and a very high performance throughout.*

AUXILIARY EQUIPMENT

Includes a Depth Gauge for use with all instruments and which will measure thicknesses between 0.1 to 4 ins. with high accuracy. Probe Holders with irrigation facilities for large surface scanning, and remote Probe Manipulators.

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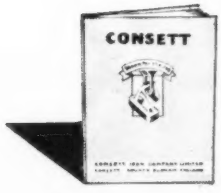

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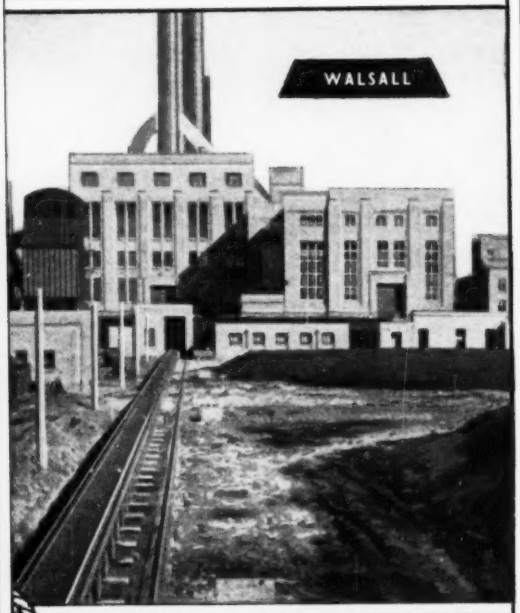

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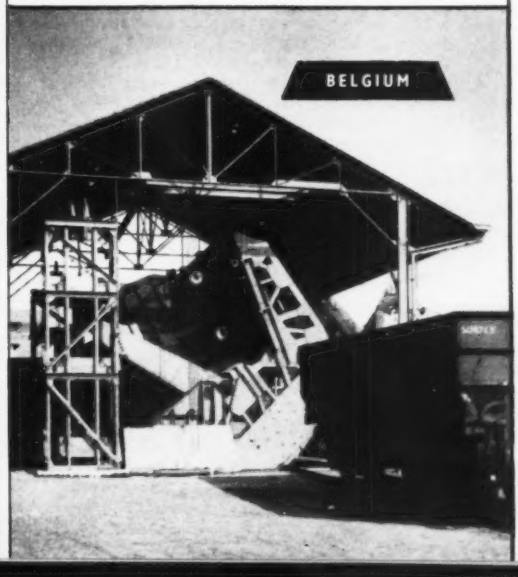
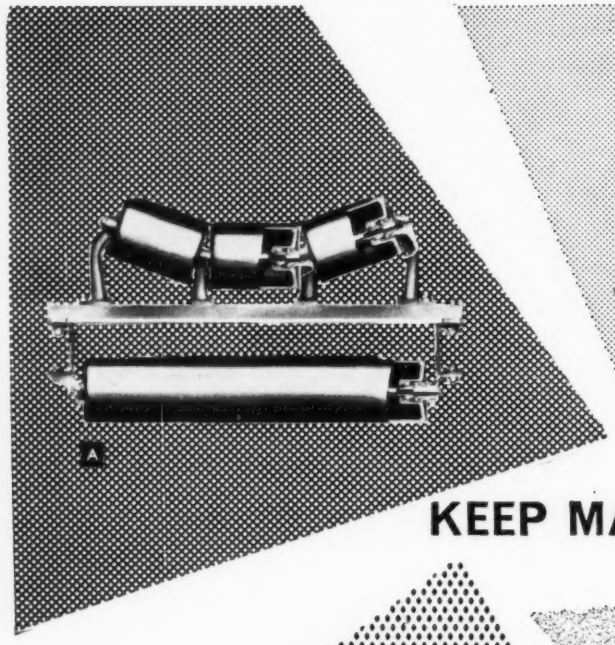
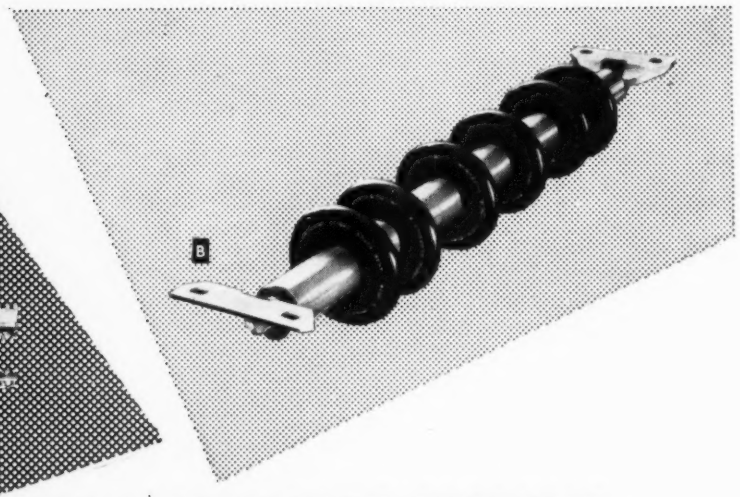
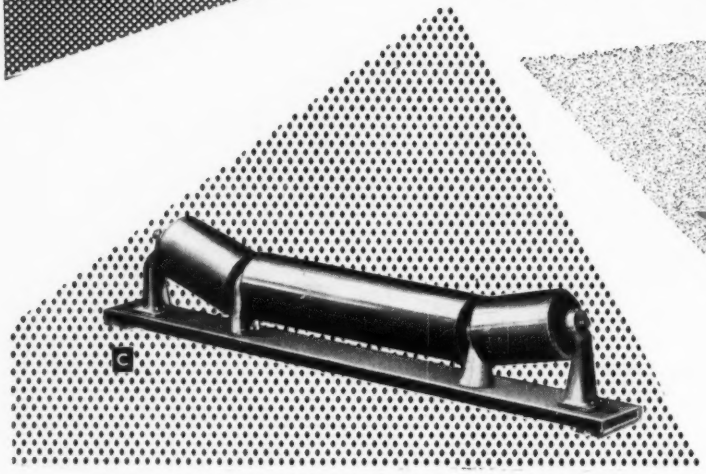
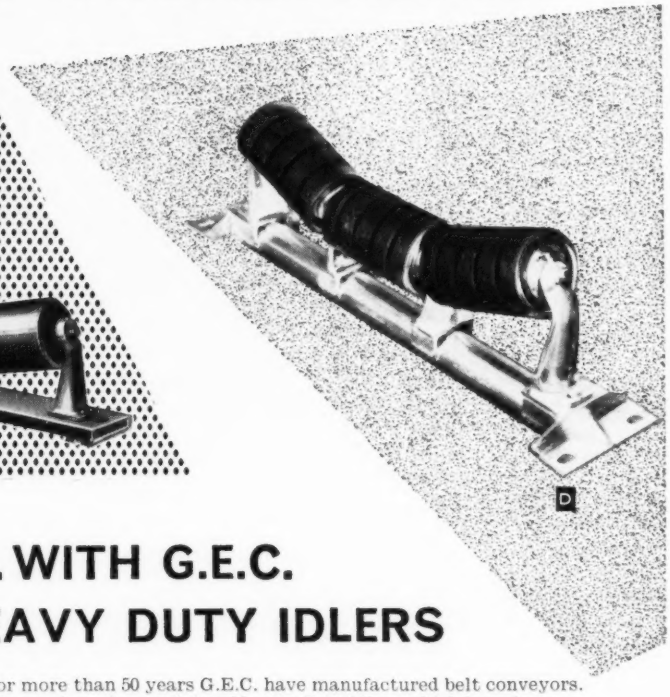






KEEP MATERIALS MOVING





A *6" diameter steel tube troughing idler and return idler.* Rollers are made from mild steel tube 6" outside dia. and 6 s.w.g. Strong, rolled section steel idler base board. All troughing idlers, except on reversible belts, provided with tilting blocks to aid training of the belt.

B *7½" diameter rubber disc return idler.* Tube carrying discs is solid drawn 6 s.w.g. and 3" outside dia. Discs are strengthened internally with mild steel ring and remain rigidly in position. Idler especially suitable where damp and sticky materials are handled.

C *6" diameter steel tube feeder idler.* Rollers are mild steel tube 6 s.w.g., and 6" outside dia. Contour of idler is designed so that material can be drawn freely from hoppers, etc., in relatively large quantities at low speeds.

D *6" diameter rubber disc impact idler.* Tube supporting discs is solid drawn ¼" thickness and 2½" outside dia. Idler base board is constructed for exceptionally arduous duties. Discs are designed to support and protect belt at loading points, cushioning shock when impact is severe.

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All components are proportioned to allow for corrosion, abrasion and normal abuse.
Special equipment can be supplied to meet abnormal conditions.

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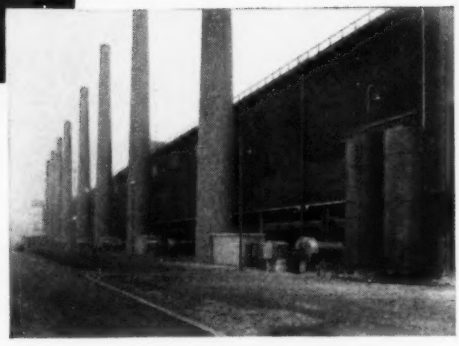
Journal of the Iron and Steel Institute

JOSEPH ADAMSON
Waste Heat Boilers



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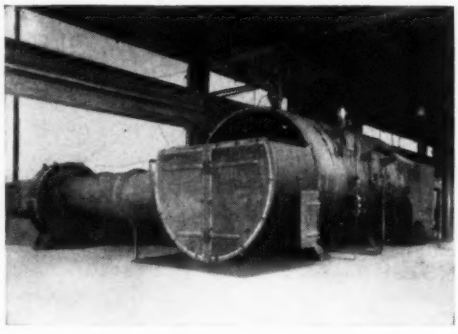
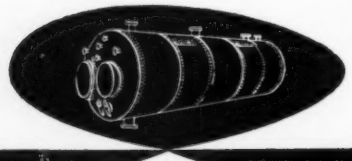
The straight-through fire tubes have a high ratio of length to bore, giving about 90% tube efficiency and providing a large area of heating surface in a comparatively small space. Brickwork setting is not required and air infiltration is thus avoided.

A feature of Joseph Adamson Waste Heat Boilers is that a special cleaning device can be provided in the outlet chamber to allow the tubes to be cleaned while the boiler is at work.





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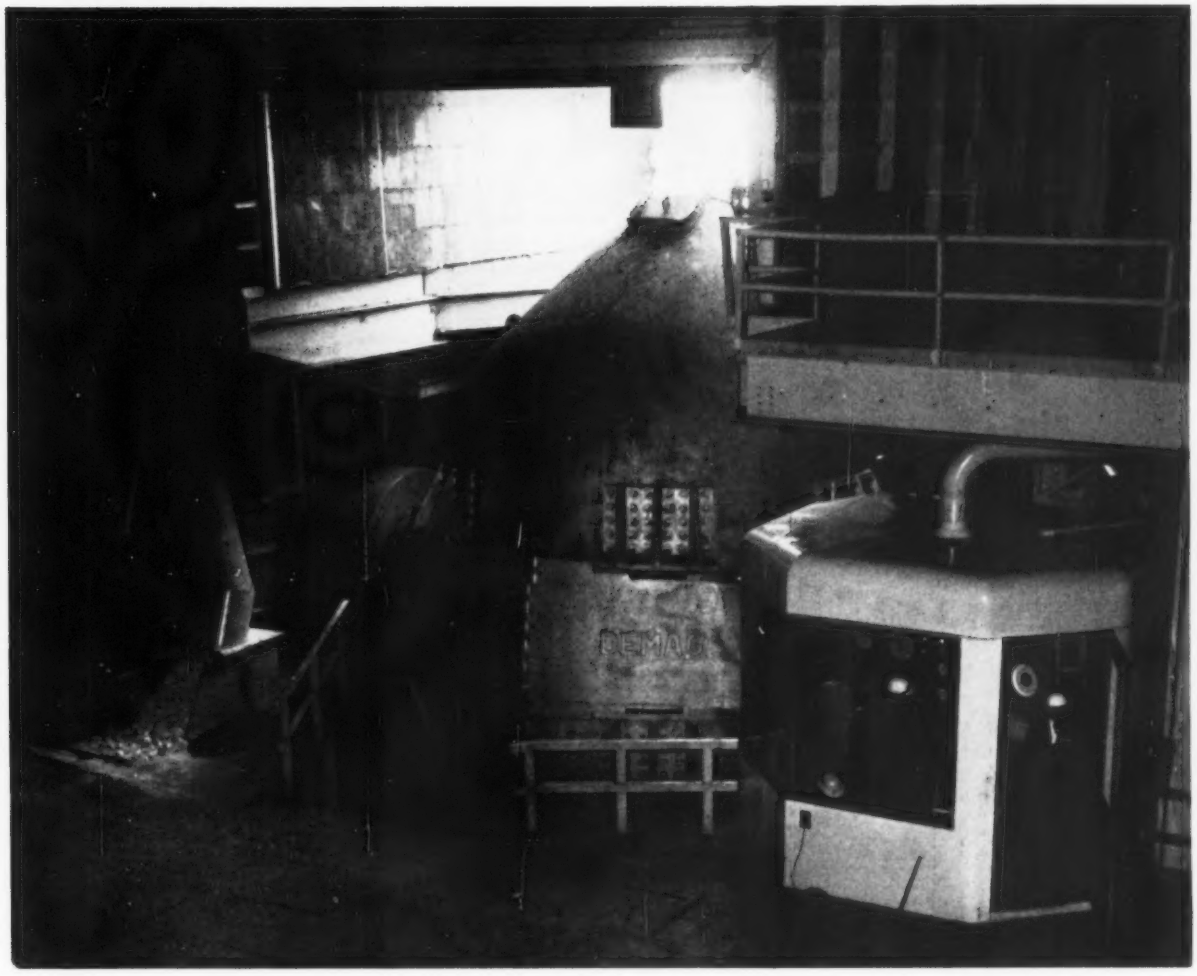

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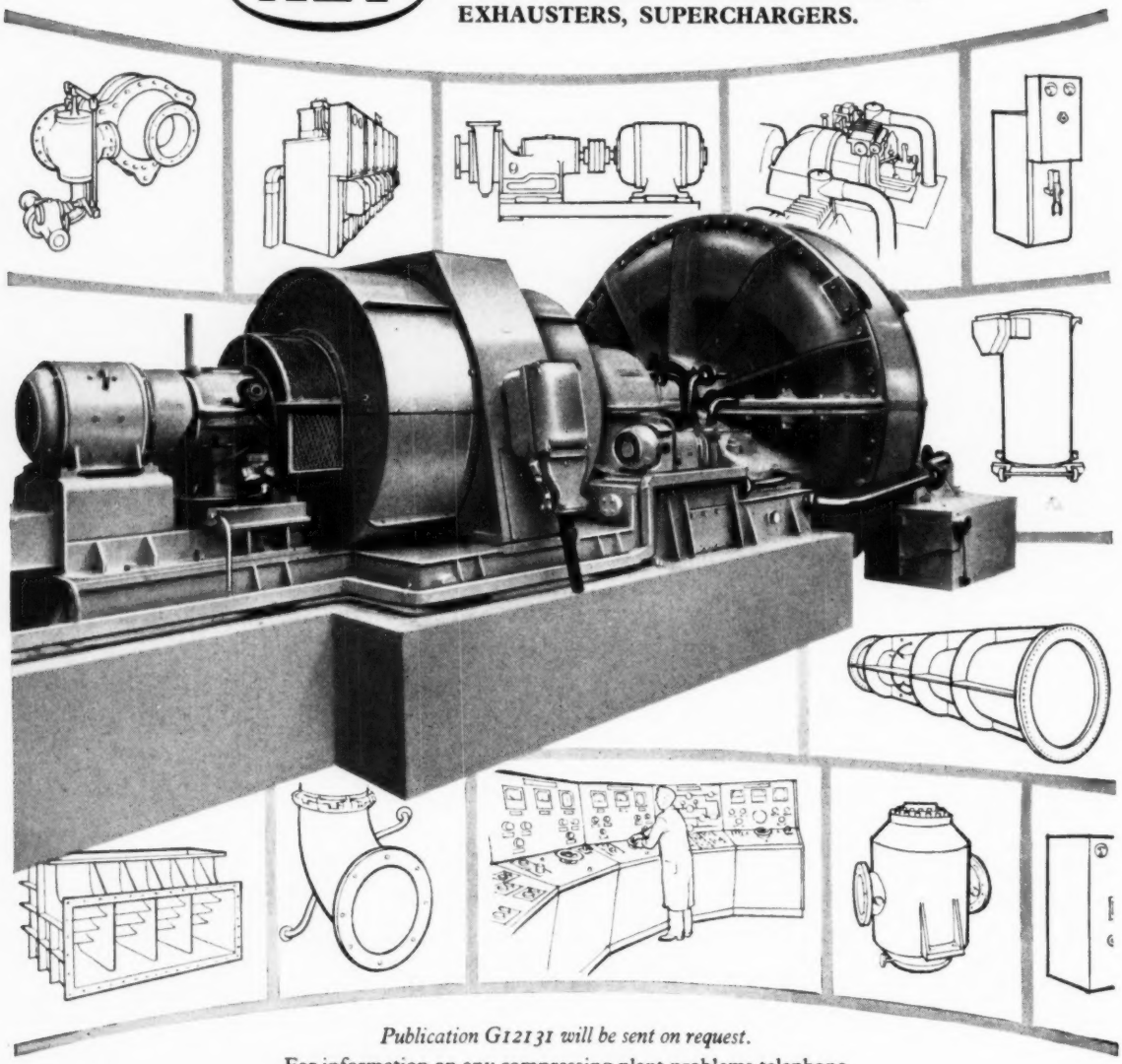

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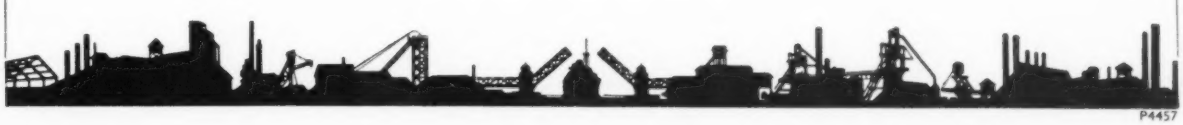

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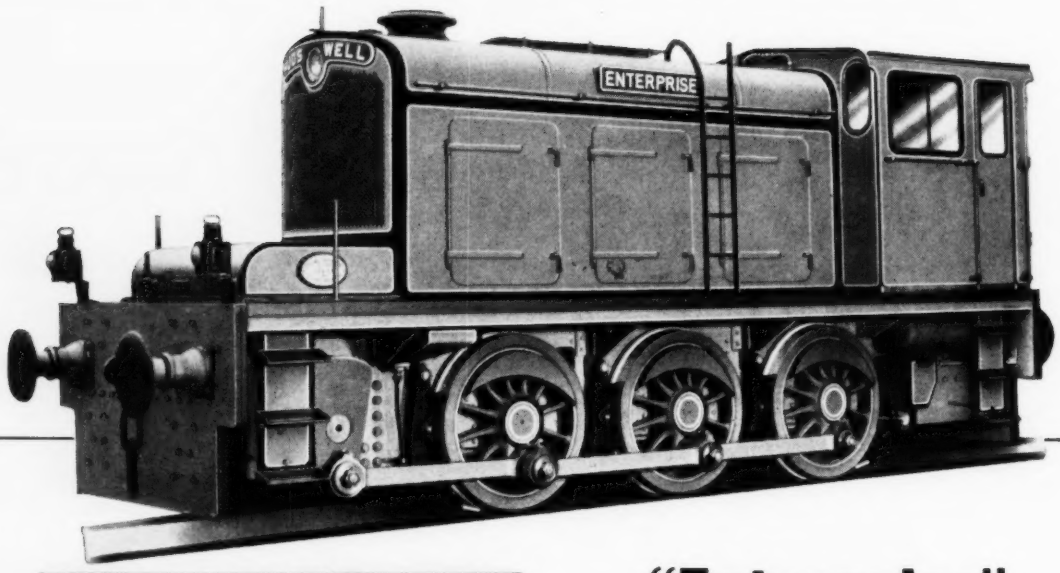

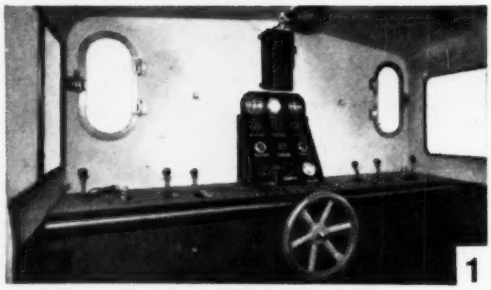
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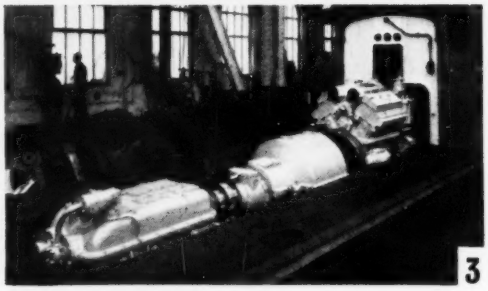
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Locomotives of this series can now be supplied in horse powers up to 1600.

1. *The cab layout. The central forward-and-reverse handle, with which is combined the high-and-low alternative ranges, is centrally located; the other controls are duplicated.*
2. *'Enterprise' at the head of a coal train.*
3. *Installation in the locomotive 'Enterprise' showing left to right, the final reduction gearbox, the Dual Fluidrive transmission, and the Paxman V-6 pressure-charged constant h.p. engine.*

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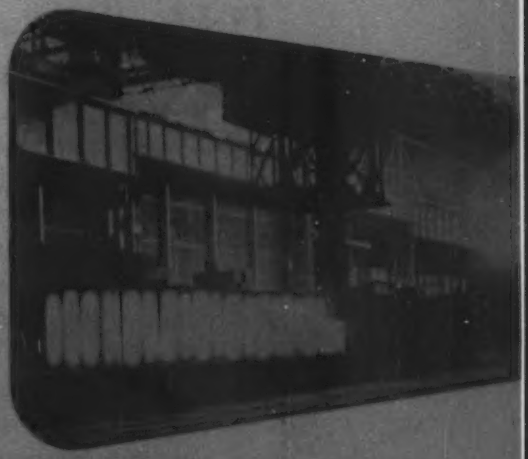

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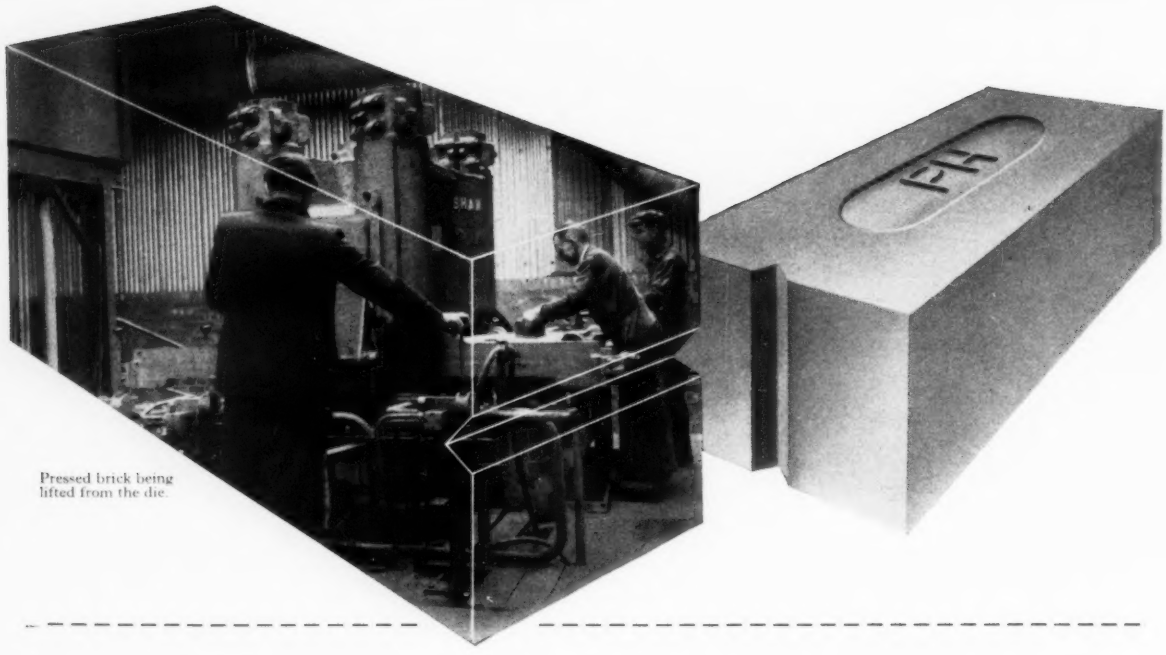

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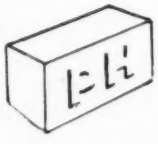

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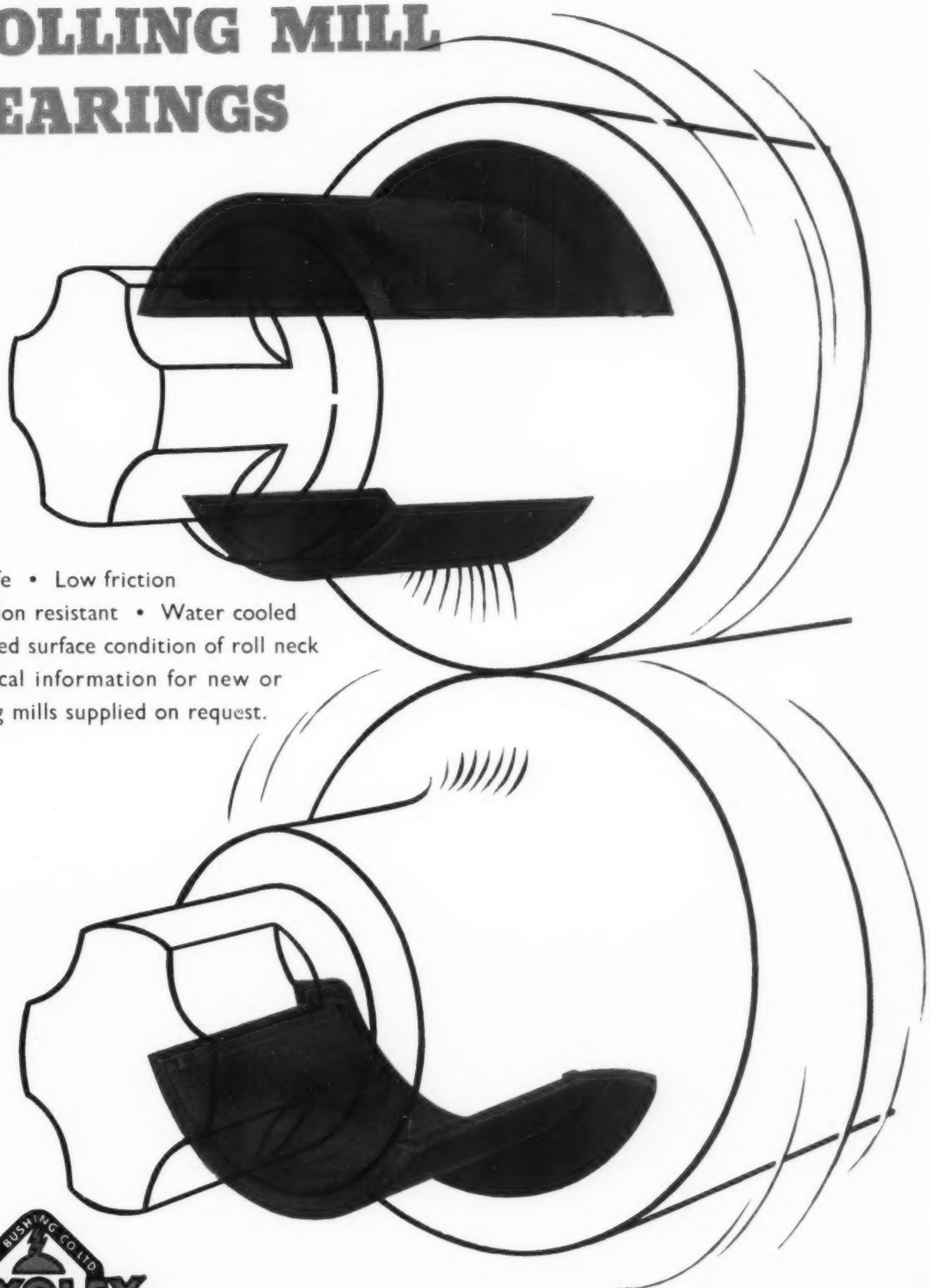

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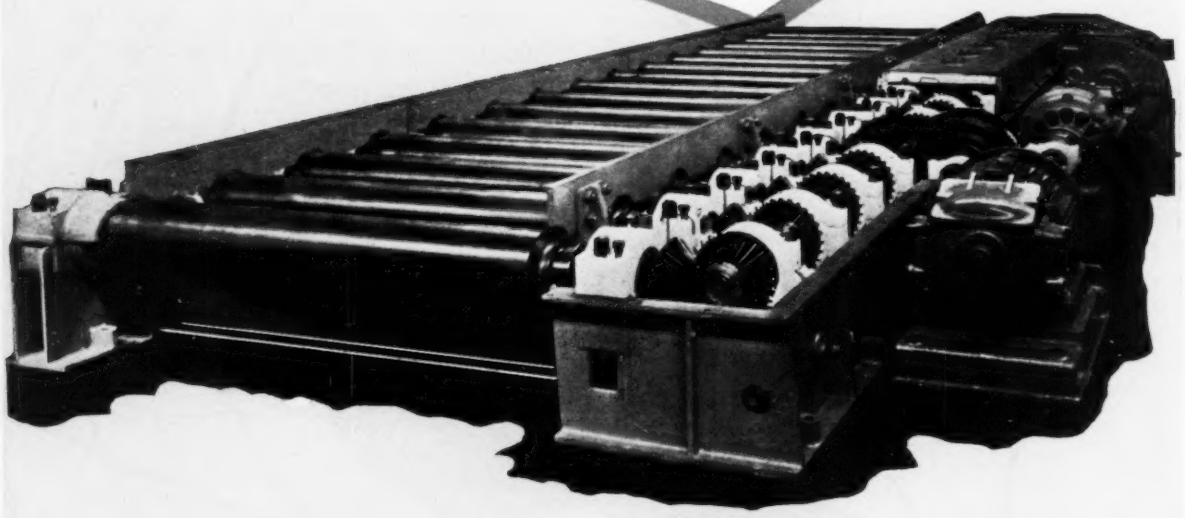

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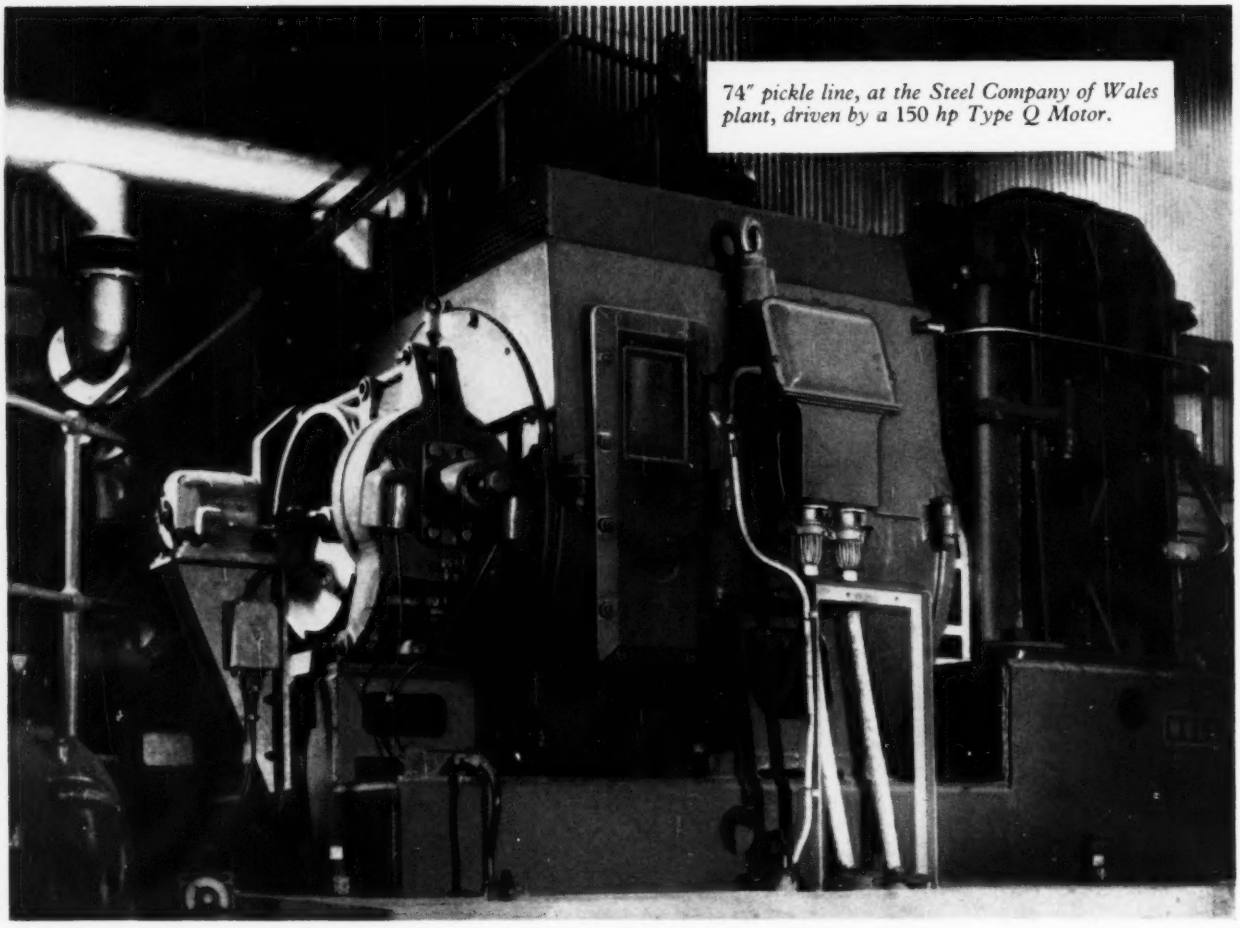

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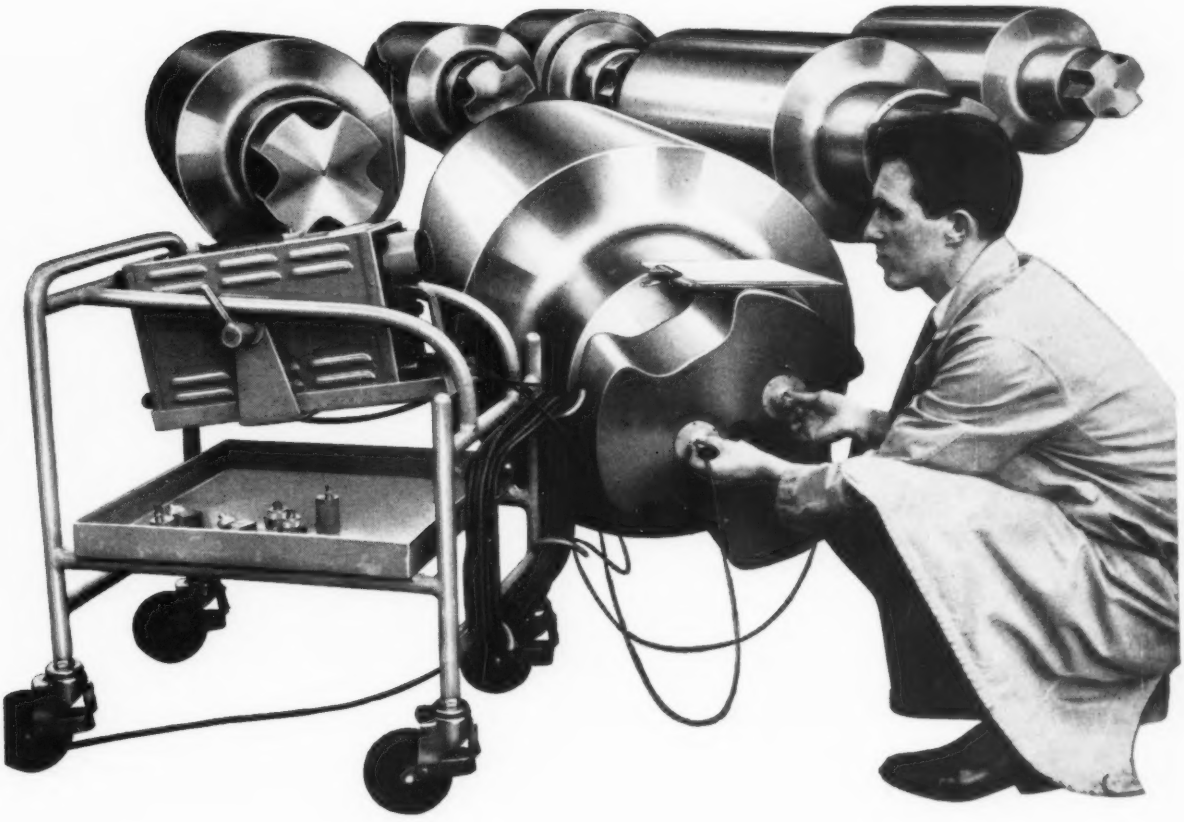

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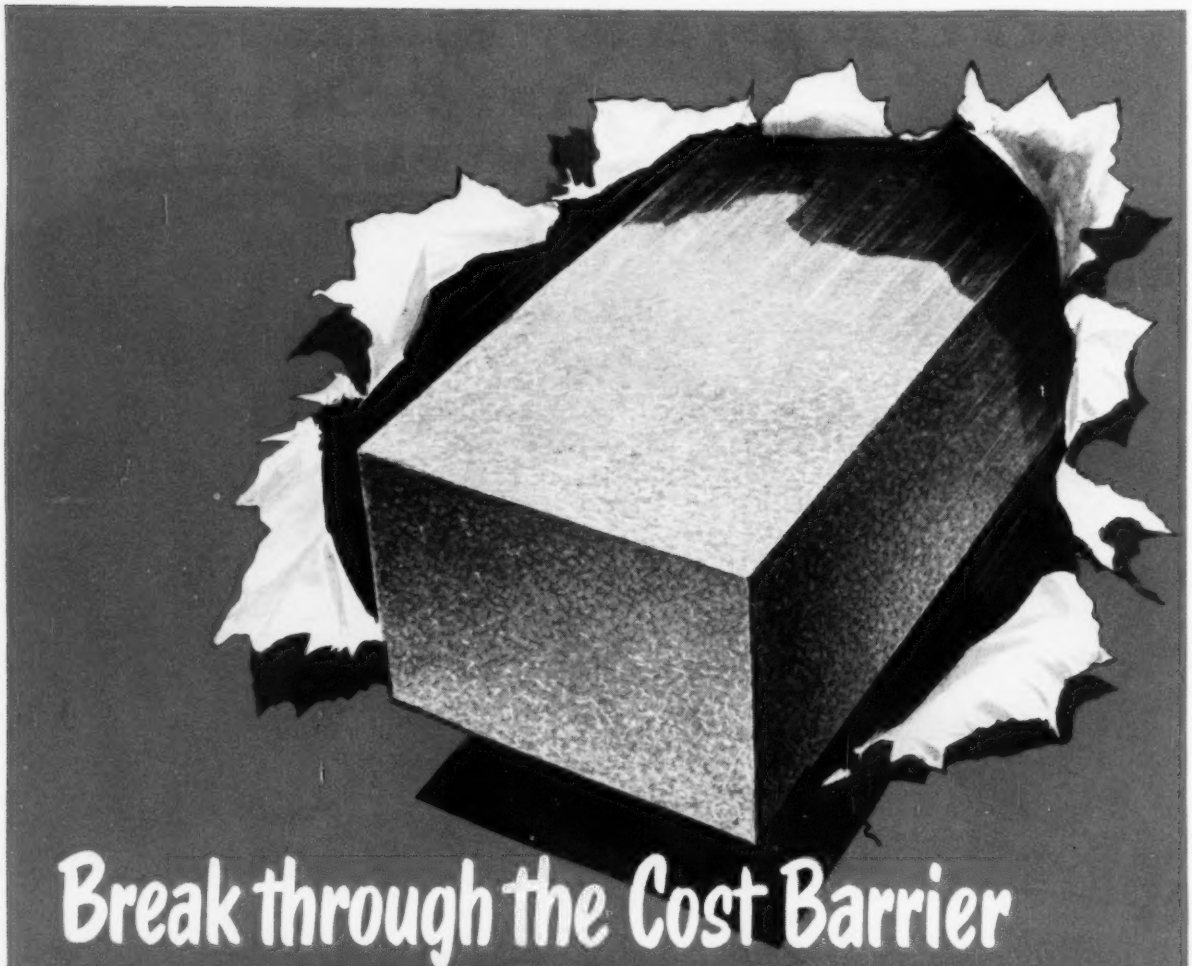

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Contents

THE IRON AND STEEL INSTITUTE

The tempering characteristics of low-carbon low-alloy steels 137
K. J. Irvine and F. B. Pickering

Some changes in the mechanical properties of mild steel caused by fatigue stressing 154
G. F. Modlen and G. C. Smith

The kinetics of first-stage graphitization in Fe–C and Fe–Co–C alloys 160
A. S. Appleton

The constitution of the iron–niobium–silicon system 169
H. J. Goldschmidt

Stress corrosion of austenitic stainless steel by high-temperature solutions and contaminated steam 181
P. P. Snowden

The accuracy of point counting in metallographic investigations 189
T. Gladman and J. H. Woodhead

LETTER TO THE EDITOR

Ergonomic investigations into the design of master controllers 168
R. G. Sell

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The spectrographic determination of residual elements in steel by the excitation index technique 193
K. M. Bills

The determination of trace elements 199
N. W. H. Addink

The gaseous reduction of fine iron ores 211
S. Y. M. Ezz and R. Wild

Liquidus–solidus relations in the system iron–aluminium 222
J. R. Lee

IRON AND STEEL ENGINEERS GROUP

Developments in electrical equipment for reversing plate mills 225
H. S. Brown and A. P. Baines

Some aspects of plate-mill design and layout 240
A. Marshall

News 249 **Translations** 252 **Abstracts** 253

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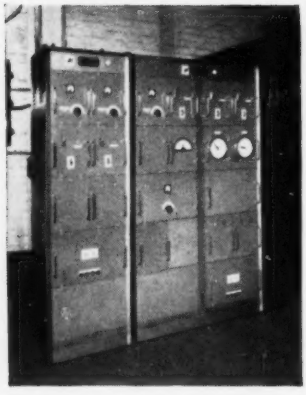

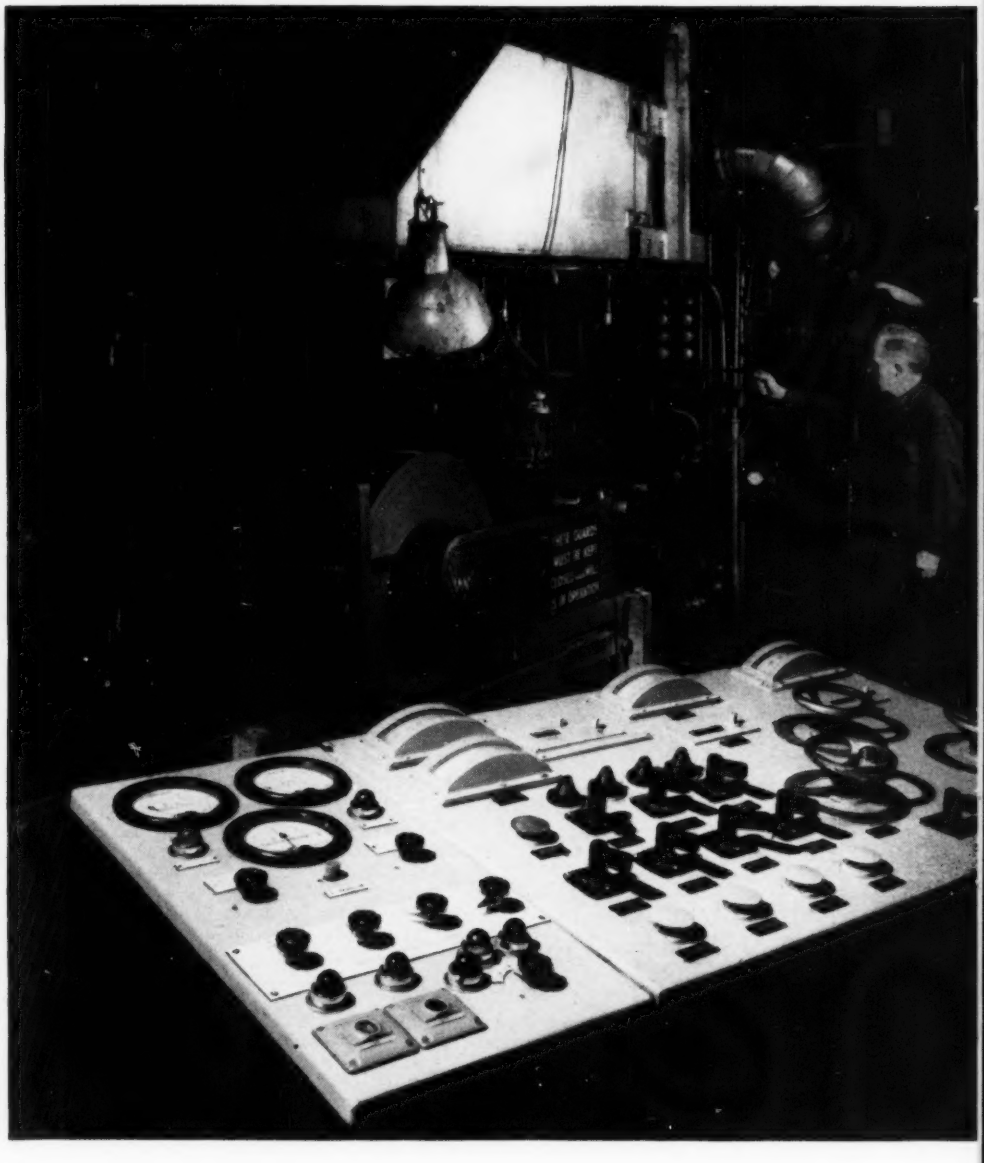

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H. BROOKE FREEMAN, O.St.J., A.R.S.M., D.I.C., F.I.M.

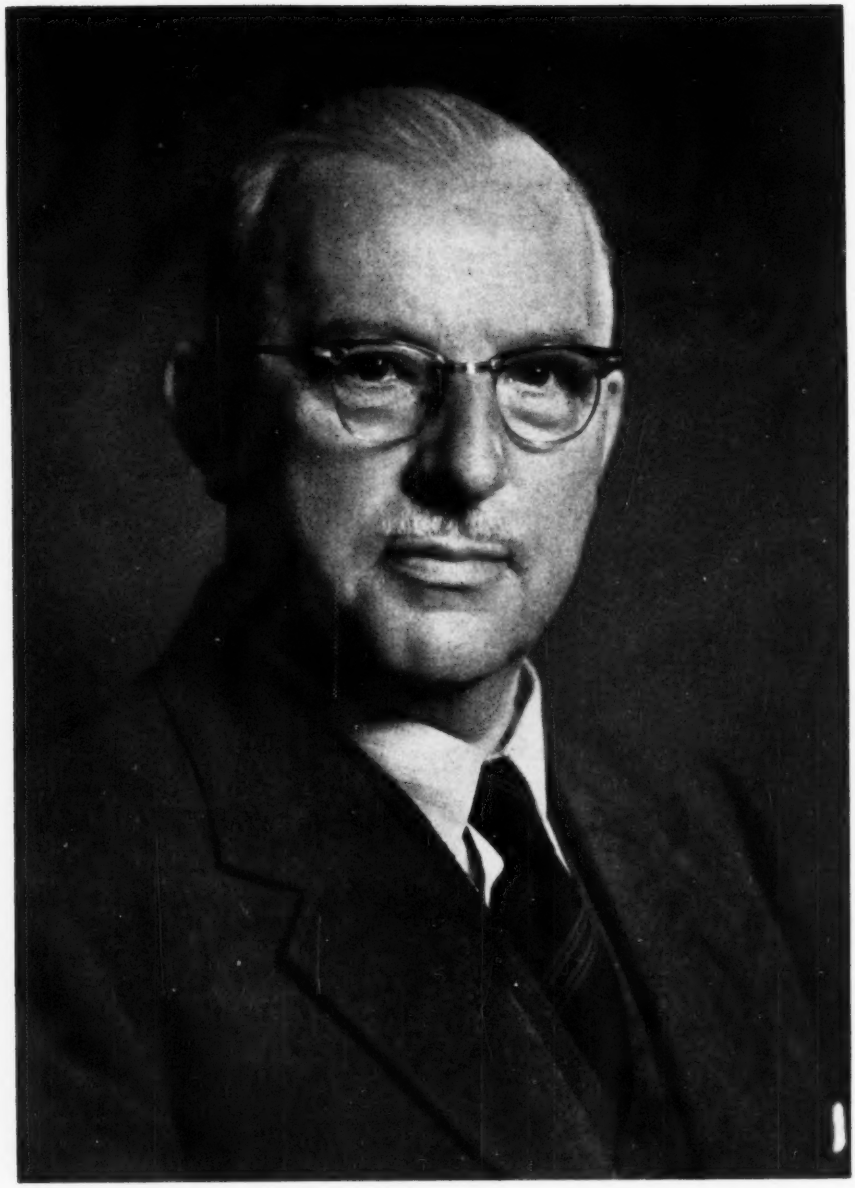
HARRY BROOKE FREEMAN attended Dudley Grammar School, Worcestershire, before joining Rubery Owen and Co. at Darlaston as assistant to the chief chemist. He continued his studies at the Staffordshire County Technical College and was awarded a special studentship to the Royal School of Mines, London, where he gained a 1st class A.R.S.M. in metallurgy. For further research work as a Frecheville Fellow of the Royal School of Mines he was awarded the D.I.C.

Mr Brooke Freeman joined John Summers and Sons Ltd in 1924 as annealing-department metallurgist, and during the next eight years he introduced new equipment and initiated extensive research in the works which resulted in patents being taken out for annealing and galvanizing plant.

In 1932 he was appointed sheet mill manager at Messrs Baldwin's Panteg works where he developed the 'Panteg' method of rolling silicon sheets. Three years later he rejoined John Summers and Sons as manager of the sheet rolling mills and the annealing, galvanizing, and packing departments. He later took charge of the former Armco department, the company's high-grade sheet mills and Sendzimir rolling and galvanizing plant. With the development of continuous rolling he reverted to research metallurgy, studying auto-body sheets from ingot making to pressing.

Mr Brooke Freeman is a founder member of the North Wales Metallurgical Society, a member of the BISRA Rolling Ingots Committee, and a Fellow of The Institute of Metallurgists. He is keenly interested in the Order of St John, and founded the John Summers Division. He was secretary of the Order in Flintshire for 15 years, became a Serving Brother in 1943, and an Officer in 1957.

Mr Brooke Freeman joined The Iron and Steel Institute in 1926, and as Chairman of the North Wales Metallurgical Society for 1958–59 he served as an Honorary Member of Council.



H. Brooke Freeman, O.St.J., A.R.S.M., D.I.C., F.I.M.

Honorary Member of Council, 1958–59

The tempering characteristics of low-carbon low-alloy steels

K. J. Irvine, B.Sc., Ph.D., and F. B. Pickering, A.Met., A.I.M.

INTRODUCTION

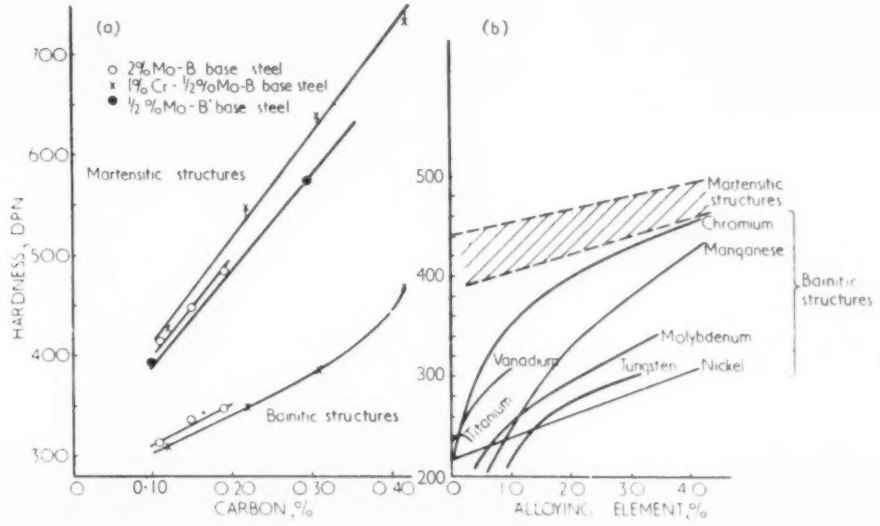
MOST ALLOY STEELS are used in the quenched and tempered condition and information about their tempering characteristics is useful in providing a background to the mechanical properties which can be obtained. For general engineering applications these steels are usually 0·3–0·4%C steels containing 2–4% of alloy addition, and there is already some information available about the effect of different alloying elements on the tempering characteristics.[1,2] Recently there has been more interest in lower carbon compositions and this has not been confined to martensitic structures only. The authors have described how it is possible to produce steels with bainitic structures covering the complete bainitic transformation range[3–5] and there has also been information about low carbon martensitic steels.[6,7]

Because of the beneficial effect of tempering on the mechanical properties of bainitic steels, particularly at the higher strength levels, it was decided to investigate the tempering characteristics of these steels systematically. It was also decided to examine these steels

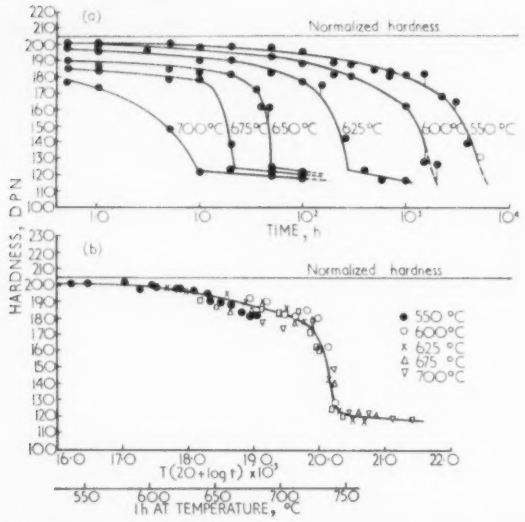
Manuscript received 25 February 1959.
Dr Irvine is Deputy Research Manager and Mr Pickering is Head of the Physical Metallurgy Section of the Research and Development Department, The United Steel Companies Ltd.

SYNOPSIS

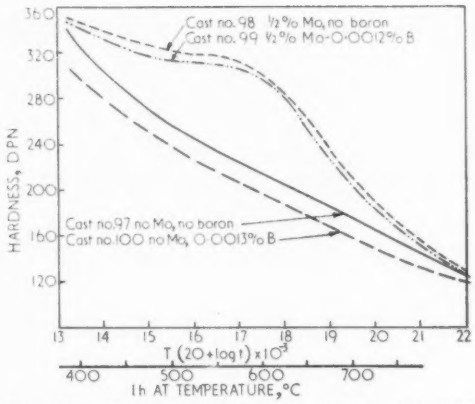
An investigation has been made of the tempering characteristics of low-carbon steels containing Mn, Ni, Cr, Mo, W, V, *and* Ti *as alloying elements. A base composition of* ½%Mo–B *was used in order to have both bainitic and martensitic structures before tempering. It was possible to distinguish clearly between the effect of* Mo, W, V, *and* T *which produced marked secondary hardening, and* Mn *and* Ni *which did not. The main feature of the microstructural examination was that the elements which produced marked secondary hardening produced separately nucleated carbides* (e.g. $Mo_2CV_4C_3$), *whereas* Mn *and* Ni *did not form a separate carbide. Chromium was intermediate in its effect because although it produced some separately nucleated carbide, the secondary hardening effect was negligible. In any steel which has a marked secondary hardening reaction, the amount of secondary hardening was decreased and the rate of secondary hardening was increased as the initial hardness level of the structure increased. It is suggested that the information obtained in this work can be used in the development of alloy steels to give the best tempering resistance at high tensile strength levels.* 1701



1 *Effect of alloy additions on the hardness of bainite and martensite (a) effect of carbon, (b) effect of separate additions of alloying elements*



2 *Tempering characteristics of 1½%Mo–B base steel, initial condition normalized,* (a) *isothermal curves,* (b) *combined time/temperature diagram*


Cast no. 98 ½% Mo, no boron
Cast no. 99 ½% Mo-0·0012% B
Cast no. 97 no Mo, no boron
Cast no. 100 no Mo, 0·0013% B
HARDNESS, D.P.N
T (20+log t) x10³
1h AT TEMPERATURE, °C

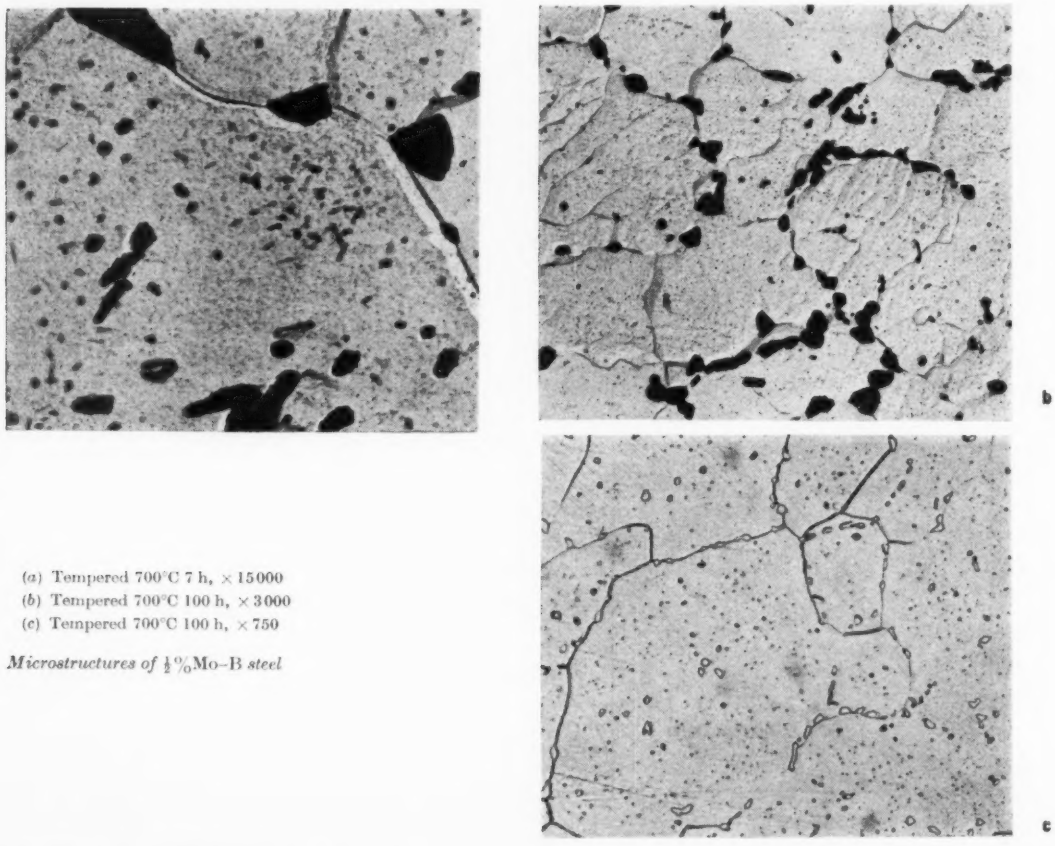
4 *The effect of boron on the tempering characteristics of low-carbon and ½%Mo steels*

in both the martensitic and bainitic conditions to show the effect of initial structure on the tempering characteristics.

This work is intended to form the background to alloy steels and future papers will show how the knowledge of the effect of alloying elements on the tempering characteristics of low-carbon steel can be used in the development of alloy steels.

THE EXPERIMENTAL STEELS

In order that a direct comparison can be made between martensitic and bainitic steels, it is necessary to select a base composition which will form bainitic structures over a wide range of alloy additions. It has been shown



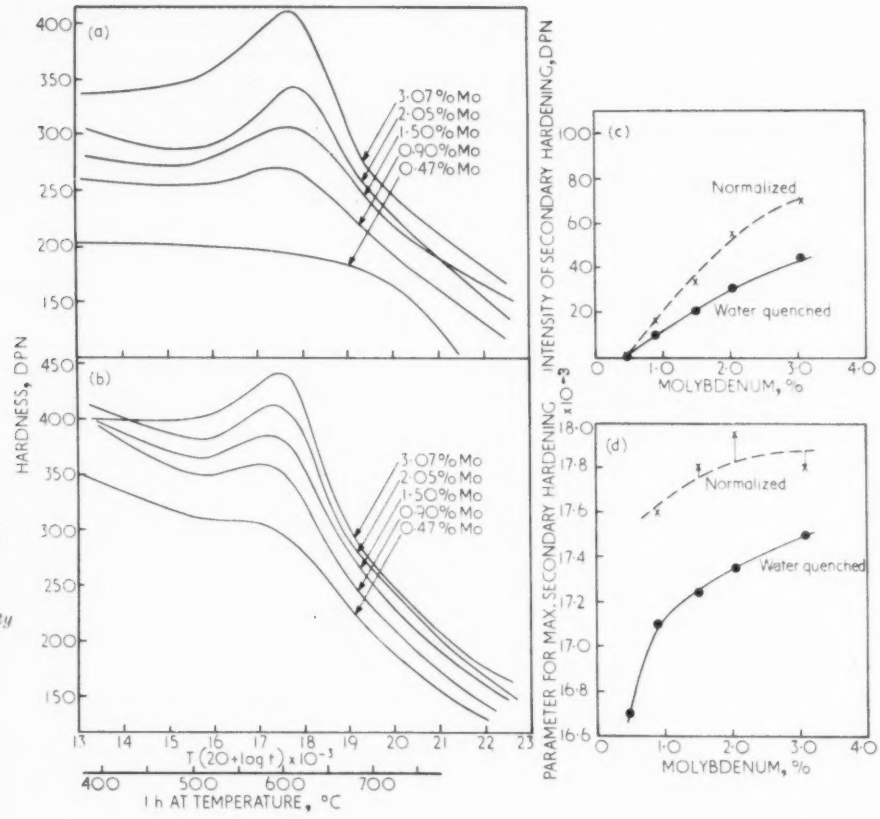
(*a*) Tempered 700°C 7 h, × 15000
(*b*) Tempered 700°C 100 h, × 3000
(*c*) Tempered 700°C 100 h, × 750

3 *Microstructures of ½%Mo–B steel*

previously that the optimum composition is 0·15%C–½%Mo–B because at normal air cooling rates this composition will form bainitic structures with up to 4% addition of the usual alloying elements. Steels containing additions of C, Mn, Ni, Cr, Mo, W, V, and Ti were used and the full chemical analyses of these steels are given in Table I. These steels were rolled to ¾-in. dia. bar and small disc specimens prepared for tempering work. The steels were austenitized at what can be considered the conventional normalizing temperature, namely Ac_3+30°C. These temperatures are given in Table I for each of the steels. This temperature is adequate to give complete solution of carbide particles except where the very strong carbide formers such as titanium are present. In such cases, however, the required solution temperature would be impracticably high, and it was the major aim in this work that the information about the tempering characteristics could

TABLE I Analyses of steels

Series	Cast No.	Analysis, % C	Mn	Si	Ni	Cr	Mo	W	V	Ti	Sol. B	Ac_3,°C	Aust. temperature, °C	Initial hardness WQ	Normalized
Base steels	99	0·12	0·59	0·12	...	0·11	0·47	...	...	...	0·0012	920	950	405	205
	621	0·13	0·57	0·09	...	...	0·47	...	...	...	0·0024	870	900	423	241
Boron	97	0·13	0·75	0·11	...	0·46	...	...	...	...	...	920	950	380	...
	98	0·12	0·69	0·10	...	0·32	0·47	...	...	...	...	920	950	393	...
	100	0·12	0·60	0·22	...	...	...	...	...	...	0·0013	920	950	399	...
Molybdenum	334	0·13	0·65	0·24	...	...	0·90	...	...	...	0·0035	805	940	408	263
	335	0·14	0·61	0·22	...	...	1·50	...	...	...	0·0024	930	960	399	275
	336	0·14	0·65	0·26	...	...	2·05	...	...	...	0·0020	935	970	410	283
	704	0·11	0·51	0·18	...	...	3·07	...	...	...	0·0028	975	1010	421	335
	806	0·11	0·94	0·08	...	1·07	0·52	...	...	...	0·0013	880	910	408	235
	807	0·11	1·00	0·09	...	1·03	1·06	...	...	...	0·0016	910	940	395	318
	808	0·11	0·99	0·13	...	1·08	2·12	...	...	...	0·0017	930	960	401	329
	809	0·11	0·94	0·08	...	1·10	3·07	...	...	...	0·0010	920	950	409	354
	819	0·10	1·51	0·10	...	1·60	0·51	...	...	...	0·0020	910	940	402	332
	820	0·09	1·67	0·26	...	1·58	0·96	...	...	...	0·0025	920	950	402	343
	821	0·09	1·45	0·14	...	1·73	1·94	...	...	...	0·0014	940	970	395	352
	822	0·09	1·55	0·17	...	1·63	2·95	...	...	...	0·0012	910	940	426	370
Tungsten	345	0·14	0·68	0·24	...	...	...	1·00	...	...	0·0044	930	960	422	213
	346	0·14	0·65	0·20	...	...	...	2·01	...	...	0·0029	970	1000	374	274
	347	0·14	0·58	0·22	...	...	...	2·98	...	...	0·0030	990	1020	385	293
Vanadium	279	0·08	0·64	0·21	...	...	0·45	...	0·10	...	0·0024	930	960	355	209
	280	0·08	0·63	0·20	...	...	0·51	...	0·29	...	0·0032	960	990	366	230
	281	0·08	0·62	0·17	...	...	0·52	...	0·46	...	0·0008	965	995	346	248
	282	0·08	0·62	0·22	...	...	0·50	...	0·59	...	0·0033	985	1015	350	256
	283	0·08	0·58	0·22	...	...	0·57	...	0·89	...	0·0027	990	1020	360	274
	810	0·11	0·98	0·10	...	1·09	0·54	...	0·07	...	0·0032	890	920	409	318
	811	0·11	0·97	0·05	...	1·06	0·51	...	0·16	...	0·0030	900	930	408	295
	812	0·11	0·96	0·10	...	1·08	0·53	...	0·35	...	0·0032	910	940	406	316
	813	0·11	1·15	0·15	...	1·13	0·50	...	0·61	...	0·0034	940	970	403	340
	814	0·12	1·13	0·16	...	1·12	0·54	...	0·91	...	0·0037	950	980	402	348
	823	0·09	1·57	0·12	...	1·59	0·56	...	0·12	...	0·0032	880	910	398	341
	824	0·09	1·50	0·14	...	1·60	0·54	...	0·20	...	0·0032	910	940	398	332
	825	0·09	1·51	0·10	...	1·57	0·52	...	0·39	...	0·0032	930	960	389	349
	826	0·09	1·62	0·18	...	1·60	0·55	...	0·63	...	0·0025	930	960	385	347
	827	0·09	1·59	0·12	...	1·63	0·54	...	0·90	...	0·0032	930	960	389	339
Titanium	284	0·08	0·51	0·17	...	...	0·50	...	...	0·023	0·0042	940	970	354	208
	285	0·08	0·56	0·18	...	...	0·51	...	...	0·060	0·0047	930	960	326	208
	286	0·08	0·54	0·17	...	...	0·51	...	...	0·12	0·0047	925	950	358	212
	288	0·08	0·51	0·11	...	...	0·51	...	...	0·24	0·0043	935	960	287	210
	289	0·08	0·63	0·19	...	...	0·51	...	...	0·38	0·0033	965	940	248	203
Chromium	264	0·06	0·67	0·19	...	0·75	0·51	...	...	...	0·0030	930	960	...	220
	265	0·06	0·81	0·30	...	1·57	0·53	...	...	...	0·0038	905	940	...	263
	720	0·17	0·69	0·18	...	0·53	0·51	...	...	...	0·0037	905	940	441	323
	721	0·18	0·69	0·22	...	1·04	0·50	...	...	...	0·0036	885	920	464	389
	722	0·18	0·71	0·25	...	2·05	0·49	...	...	...	0·0021	865	900	472	399
	723	0·18	0·72	0·26	...	3·04	0·48	...	...	...	0·0036	850	880	503	452
	724	0·18	0·77	0·33	...	4·09	0·48	...	...	...	0·0030	850	880	495	464
Manganese	210	0·15	0·85	0·14	...	...	0·54	...	...	...	0·0032	875	900	...	225
	622	0·14	1·20	0·17	...	...	0·48	...	...	...	0·0032	880	910	425	334
	211	0·17	1·42	0·20	...	...	0·52	...	...	...	0·0023	865	900	...	266
	330	0·15	1·90	0·24	...	...	0·50	...	...	...	0·0035	885	910	...	324
	331	0·14	2·95	0·29	...	...	0·55	...	...	...	0·0034	865	900	...	370
	332	0·14	4·00	0·26	...	...	0·55	...	...	...	0·0031	865	890	445	422
Nickel	443	0·15	0·60	0·20	1·00	...	0·51	...	...	...	0·0007	860	890	434	239
	115	0·11	0·38	0·10	1·45	...	0·51	...	...	...	0·0018	890	920	...	224
	445	0·16	0·60	0·21	1·96	...	0·50	...	...	...	0·0013	850	880	441	282
	116	0·11	0·40	0·04	2·02	...	0·50	...	...	...	0·0023	885	920	...	228
	156	0·09	0·48	0·10	3·04	...	0·54	...	...	...	0·0025	830	860	...	275
	155	0·12	0·48	0·10	3·99	...	0·54	...	...	...	0·0028	835	860	...	289
Carbon	706	0·11	0·54	0·14	...	...	2·14	...	...	...	0·0022	960	990	415	313
	707	0·15	0·66	0·24	...	...	2·10	...	...	...	0·0031	940	970	447	335
	708	0·19	0·63	0·23	...	...	2·05	...	...	...	0·0034	985	1010	484	346
	741	0·12	0·52	0·27	...	1·08	0·54	...	...	...	0·0038	900	930	428	309
	742	0·22	0·57	0·21	...	1·05	0·51	...	...	...	0·0038	830	860	545	350
	743	0·31	0·63	0·29	...	1·03	0·49	...	...	...	0·0024	820	850	632	384
	744	0·42	0·59	0·28	...	0·99	0·54	...	...	...	0·0028	805	840	735	468



5 *The effect of molybdenum on tempering characteristics* (a) *hardness, normalized,* (b) *hardness, water quenched,* (c) *effect on the intensity of secondary hardening,* (d) *effect on the parameter for maximum secondary hardening*

be applied to commercial steels, and commercial tempering conditions. The initial hardnesses were determined before tempering and these values are given in Table I. Tempering was carried out at temperatures between 400° and 750°C on the steels in both the normalized and water-quenched conditions.

EXPERIMENTAL RESULTS

The effect of alloying elements on the initial hardness

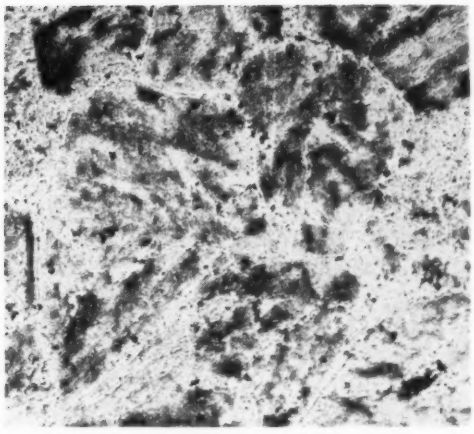
To assess the effect of alloying elements on tempering characteristics it is necessary to know the effect of these elements on the initial structure. In many cases, the effect of the alloying element may be accentuated by the variation in the initial structure. It is known that carbon has a marked effect on both martensitic and bainitic structures and it is inevitable that there is some variation in carbon in these experimental steels. An allowance has therefore been made for this variation of carbon before assessing the effect of the alloying elements.

The effect of carbon is shown in Fig.1*a* and it will be seen that there is a marked effect in both structures. In the martensitic structure the increasing hardness is mainly due to the solid solution hardening effect of carbon and the effect is linear over the carbon range studied. In the bainitic structure, the effect is due to the depression of the transformation temperature and the associated finer grain size and increased carbide particle dispersion. The effect is linear up to 0·3%C, and above this amount the more rapid increase in hardness is probably due to the formation of some martensite.

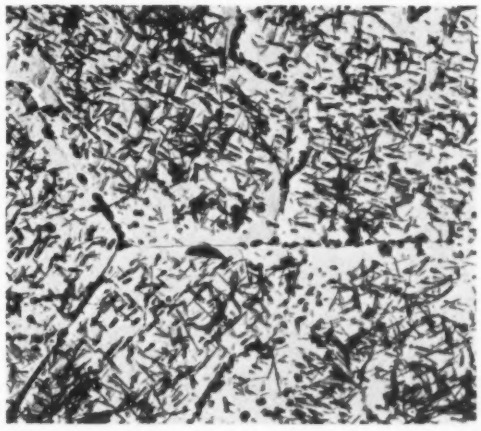
With the effect of carbon known, it is possible to correct the hardness values of all the other steels to represent a constant carbon content of 0·15%C. Using these corrected results, the effect of the different alloying elements is shown in Fig.1*b*. It will be seen that the effect on the martensitic hardness level is only slight and results from the solid solution hardening effect of the alloying elements. There is a much greater effect on the bainitic hardness level due to the combination of the effect of depressing the transformation temperature together with a solid solution hardening effect. The effect is not linear but a comparison can be obtained by considering the effect of the first 1% of alloy addition.

Alloy addition	Hardness increase, DPN
0·1%C	43
1%Mn	96
1%Ni	23
1%Cr	136
1%Mo	64
1%W	60
1%V	90

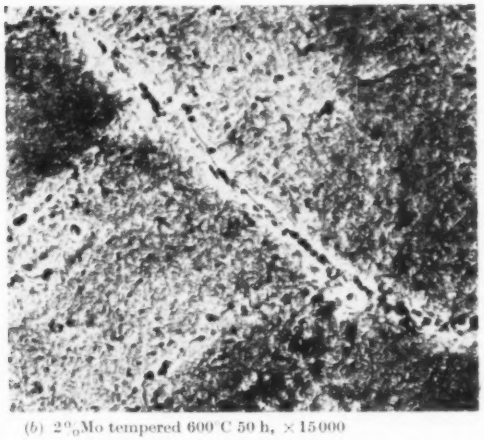
Knowledge of the relative effects of these alloying elements is very useful when developing bainitic steel compositions.



(*a*) 2%Mo tempered 600°C 20 h, ×3000



(*c*) 2%Mo tempered 700°C 1 h, ×15000



(*b*) 2%Mo tempered 600°C 50 h, ×15000

(*d*) 3%Mo tempered 750°C 100 h, ×15000

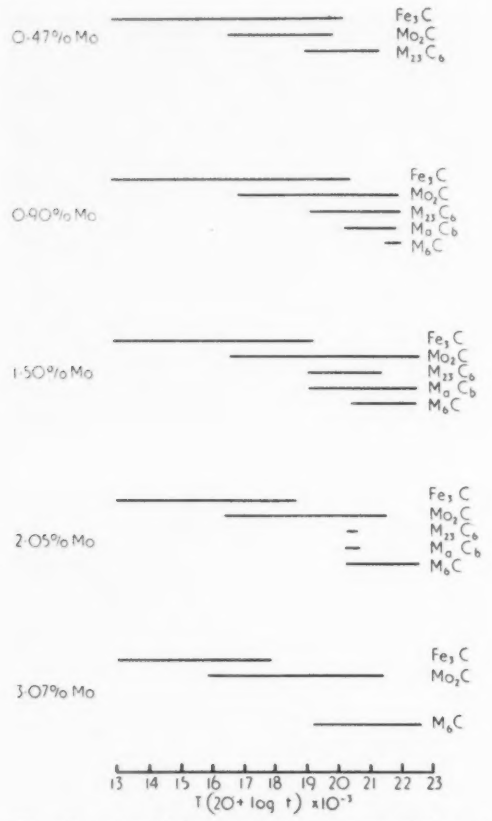
6 *Microstructures obtained after tempering* Mo–B *steels which were initially in the bainitic condition*

THE TEMPERING CHARACTERISTICS OF THE BASE COMPOSITION

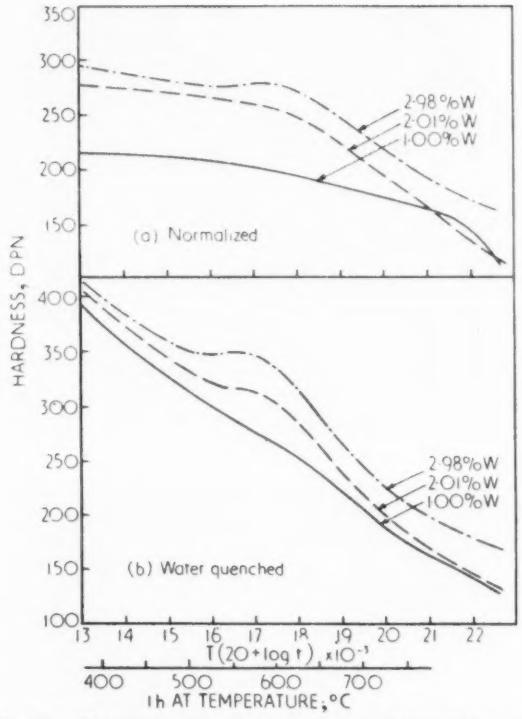
The common base composition for the martensitic and bainitic structures is $\frac{1}{2}$%Mo–B and isothermal tempering curves for this steel in the bainitic condition are given in Fig.2*a*. Below 550°C the hardness does not decrease appreciably with tempering times up to 1000 h. At higher temperatures the hardness changes considerably within the 1000-h period in a manner which is very dependent upon temperature. All of the curves however, show a slight hardness decrease at short tempering times, followed by a stage of major softening which reduces the hardness to 120–130 DPN, following which the hardness remains relatively constant.

It is possible to combine all this tempering data on one curve using a combined time/temperature parameter of the form derived by Holloman.[8] A typical curve of this type is shown in Fig.2*b* which demonstrates how it is possible to represent the data by a single curve, without too much scatter in the results. The most convenient form of the combined time/temperature parameter has been found to be $T\,(20+\log t)$ where T is the tempering temperature, °K, and t is the time in hours. The constant 20 has been found most suitable for the low-carbon steels in this work and this parameter is adhered to throughout the paper. It is appreciated that the method is not accurate when secondary hardening reactions are being considered and therefore isothermal tempering curves are also available for each of these steels to substantiate the conclusions drawn from the combined time/temperature tempering curves.

In this $\frac{1}{2}$%Mo–B steel, the retarded softening is due to the persistence of the acicular bainitic ferrite grains and the formation of Mo_2C precipitates in the grains. The electron micrograph in Fig.3*a* shows the needle-like Mo_2C after it has started to coarsen and the hardness has decreased. This electron micrograph was obtained by the carbon extraction technique as were the others shown in this paper. The softening is accompanied by coalescence of the Fe_3C and replacement of Fe_3C by $M_{23}C_6$ carbides at the prior austenite grain boundaries as shown in Fig.3*b*. This occurs with a gradual disappearance of the Mo_2C precipitate and is also associated with a recrystallization of the ferrite so that large equiaxed grains are formed, as shown in the optical micrograph in Fig.3*c*. It is this recrystallization process which is responsible for the rapid softening. Similar microstructural changes during tempering have been shown by Smith and Nutting.[9]



7 *The effect of molybdenum on the occurrence of the various carbide types during tempering*



8 *The effect of tungsten on the tempering characteristics* (a) *hardness, normalized,* (b) *hardness, water quenched*

THE EFFECT OF ALLOYING ELEMENTS ON THE TEMPERING CHARACTERISTICS

Boron

Since boron is an essential element for producing the bainitic structure, it is only possible to study the effect of boron on a martensitic structure. The effect of boron was examined both in a plain carbon and a ½%Mo steel. The tempering curves are shown in Fig.4 and when due allowance is made for an incidental chromium content it will be seen that boron has no effect on the tempering resistance. There were identical microstructures in the steels with and without boron after equivalent tempering treatments.

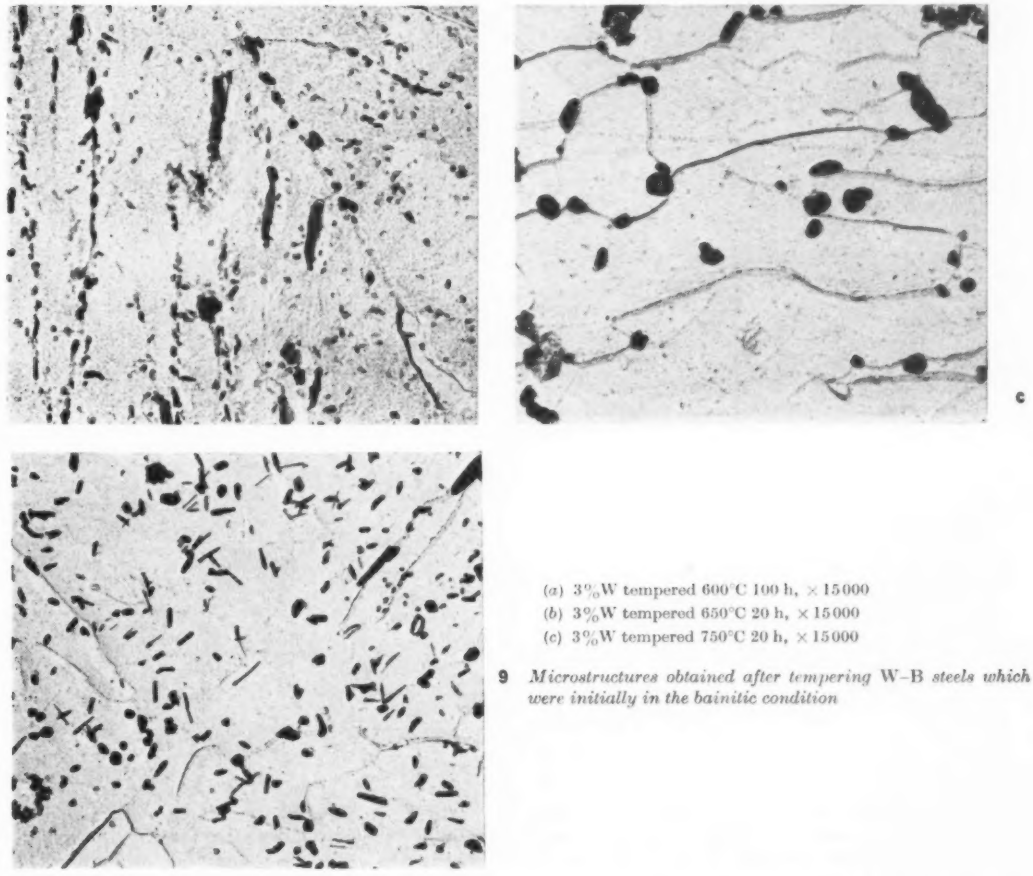
Molybdenum

The effect of ½%Mo in the martensitic condition can be seen in Fig.4 and this clearly shows retarded softening due to a secondary hardening reaction. The ½% Mo addition is necessary to produce a bainitic structure, and consequently a Mo-free steel cannot be examined with a bainitic structure.

The effect of molybdenum up to 3% was investigated and the main features of the tempering curves are summarized in Fig.5. It will be seen that both the martensitic and bainitic curves have similar features. In amounts above ½%, molybdenum introduces marked secondary hardening, and the amount of secondary hardening increases with increasing molybdenum. In assessing these tempering curves the amount of secondary hardening is taken as the difference in hardness between the minimum before secondary hardening and the peak hardness. The effect of molybdenum on the amount of secondary hardening is summarized in Fig.5*c*. The amount of secondary hardening is greater in the bainitic than in the martensitic condition. The tempering parameter value at which maximum secondary hardening occurs is a measure of the speed of the hardening reaction. A summary of the effect of molybdenum on this is shown in Fig.5*d* which indicates that increasing molybdenum slows down this process, or alternatively, causes it to occur over a wider temperature range so that the maximum effect occurs at a higher temperature or longer time.

The secondary hardening process is accompanied by the formation of a very fine precipitate of Mo_2C. This is shown for a bainitic steel in Fig.6*a* where it will be seen that the Mo_2C precipitation occurs together with a re-solution of the large Fe_3C particles which were in the initial structure. A similar precipitate occurs in the martensitic structure but here there are smaller initial Fe_3C particles. Maximum secondary hardening occurs just before small needles are observed in the microstructure (Fig.6*b*) and when rapid softening occurs after the peak of the hardening process, the Mo_2C needles coarsen into a clearly defined Widmanstätten structure (Fig.6*c*). This precipitation of Mo_2C was observed in each of the steels and it was noticed that the number of Mo_2C particles increased as the molybdenum content increased which is probably the reason for the increasing amount of secondary hardening.

The carbide changes during overageing are not simple. Three more highly alloyed carbides form,



(*a*) 3%W tempered 600°C 100 h, ×15000
(*b*) 3%W tempered 650°C 20 h, ×15000
(*c*) 3%W tempered 750°C 20 h, ×15000

9 *Microstructures obtained after tempering* W–B *steels which were initially in the bainitic condition*

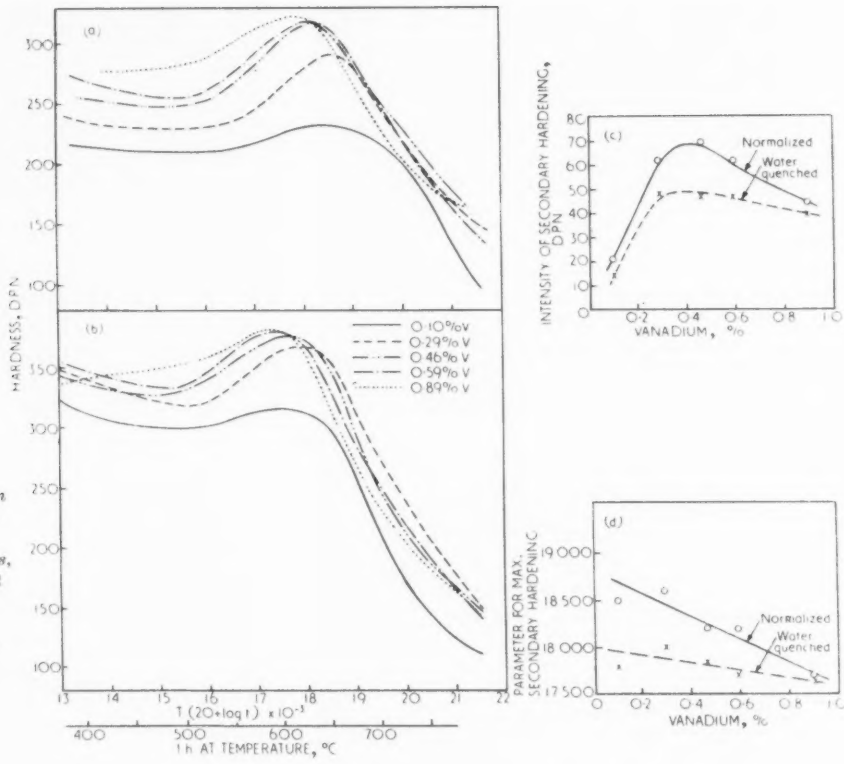
namely $M_{23}C_6$, M_aC_b[10], and M_6C. Previous reference has been made to the existence of an M_aC_b carbide form by Kuo[10] and Seal and Honeycombe.[14] At 1%Mo and above the equilibrium carbide is M_6C, which forms at long times and high temperatures, but two transitional carbides M_aC_b and $M_{23}C_6$ can form during the approach to equilibrium. An indication of the range of stability of these intermediate carbides, which are clearly observed in the 1% and 1½%Mo steels, but are not present above 2%Mo, is given in Fig.7. Generally, the $M_{23}C_6$ and M_6C particles occur at the grain boundaries as shown in Fig.6*d*. These particles grow rapidly while the Mo_2C needles redissolve. This is accompanied by very marked softening and by recrystallization of the matrix ferrite.

Tungsten

It has been shown previously[2] that tungsten can replace molybdenum so that 1%W–B is a suitable base composition for bainitic steels. It is also known that tungsten has similar characteristics to molybdenum as an alloying element. It was therefore decided to investigate the tempering characteristics of W–B steels containing up to 3%W. The tempering curves are shown in Fig.8. As the tungsten increases, the softening is increasingly retarded and 3%W produces true secondary hardening. It will be seen, therefore, that the general effect is similar to that of molybdenum and secondary hardening is obtained at roughly the same tempering parameter. The secondary hardening effect of tungsten is much less than that of molybdenum however, as a comparison between Figs.5 and 8 shows. In the 3%W steel the microstructures are similar to those obtained in the molybdenum steels, with secondary hardening resulting from a fine dispersion of W_2C (Fig.9*a*) which, during overageing, develops into plates or needles of W_2C in a Widmanstätten structure (Fig.9*b*). During the rapid softening stage, both $M_{23}C_6$ and M_6C form at the grain boundaries (Fig.9*c*) until finally with tempering temperatures of 700° and 750°C the $M_{23}C_6$ is completely replaced by M_6C. The smaller effect of tungsten appears to be due to a lower density of W_2C precipitate.

Vanadium

Vanadium is well known as an element which confers marked secondary hardening on steels and the effect of up to 1%V addition to the ½%Mo–B base has been examined. The tempering curves are shown in Fig.10 from which it can be seen that vanadium produces marked secondary hardening even at the 0·1% level. The effect then becomes very marked with increasing vanadium. It is when such marked secondary hardening occurs, that criticism might particularly be directed at the use of combined time/temperature parameters. Full isothermal tempering curves were determined on all these steels to confirm any conclusions



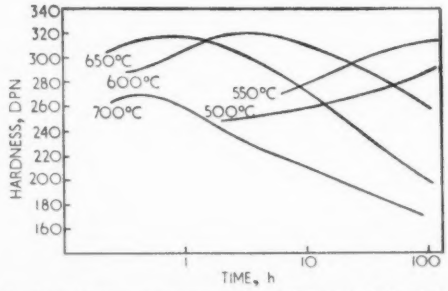
10 *The effect of vanadium on tempering characteristics* (a) *hardness, normalized,* (b) *hardness, water quenched,* (c) *effect on the intensity of secondary hardening,* (d) *effect on the parameter for maximum secondary hardening*

drawn and a typical set of these curves for the 0·59%V steel in the normalized condition is given in Fig.11. Very similar measurements for the amount of secondary hardening and the tempering conditions for maximum secondary hardening would be obtained from these curves as from the combined time/temperature parameter curves.

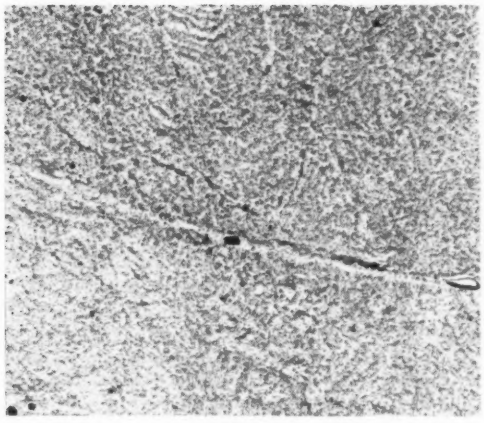
From the summaries of the main features which are given in Fig.10 it will be seen that the tempering parameter for maximum secondary hardening decreases with increasing vanadium, but the range is from 18600 to 18000 in the normalized condition and 18000–17300 water quenched, which is higher than for the secondary hardening produced by molybdenum (17950–17600 normalized and 16700–17500 water quenched). Once again secondary hardening occurs more rapidly in the water-quenched condition than when normalized (i.e. martensitic compared with bainitic). It appears that the first addition of vanadium increases the amount of secondary hardening, but above 0·5%V this decreases again.

The secondary hardening effect is associated with the formation of a fine dense precipitate of V_4C_3 (Fig.12*a*) at which stage the Fe_3C particles present in the initial structure are re-dissolving. During overageing, these V_4C_3 particles coarsen and form plates in a Widmanstätten pattern (Fig.12*b*). In the lower-vanadium steels the V_4C_3 particles are spheroidal but become more platelike as the vanadium content increases. With further tempering the V_4C_3 plates grow into slabs and the grain boundary V_4C_3 also coarsens (Fig.12*c*). When the vanadium content is only 0·1% however, $M_{23}C_6$ also forms as very coarse particles at the grain boundaries (Fig.12*d*) but above 0·29%V the $M_{23}C_6$ does not form. Presumably, this is due to the influence of molybdenum when the V/Mo ratio is low.

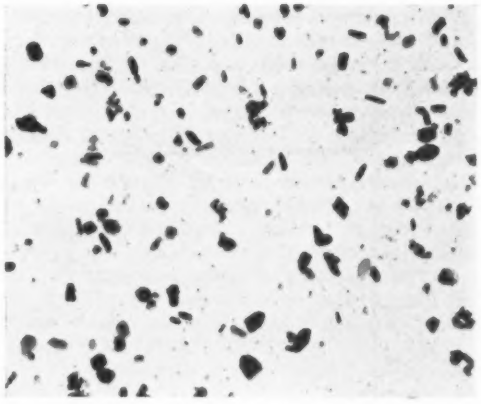
The maximum in secondary hardening occurs at approximately 0·4%V or a V/C ratio of 3:1. From the electron microstructures it is difficult to see a reason for this, although the precipitated V_4C_3 particles do become coarser with the higher vanadium contents. It seems most likely that the critical amount of vanadium for maximum secondary hardening is related to the degree of misfit between the V_4C_3 lattice and the ferrite. Lattice parameter measurements of the V_4C_3 formed in the steels of varying vanadium content show a marked variation with the Mo/V ratio and by comparison with results of Krainer[11] it can be concluded that at low vanadium levels up to 40 at.-%Mo is present in the V_4C_3. By applying the orienta-



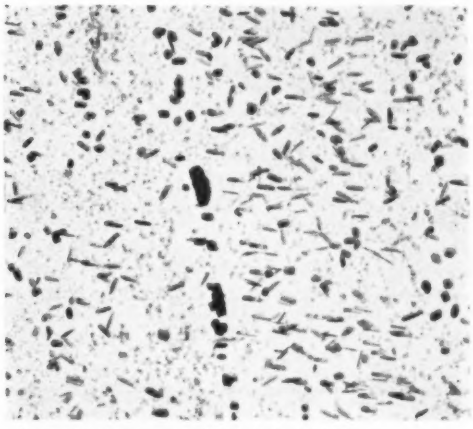
11 *Isothermal tempering curves for 0·59%V–½%Mo steel*



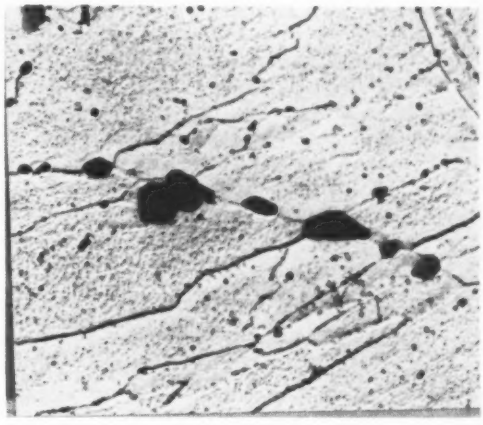
(*a*) 0·59%V tempered 650°C 20 min, ×15000



(*c*) 0·59%V tempered 700°C 100 h, ×15000



(*b*) 0·46%V tempered 700°C 10 h, ×15000



(*d*) 0·10%V tempered 700°C 1 h, ×15000

12 *Microstructures obtained after tempering* V–Mo–B *steels which were initially in the bainitic condition*

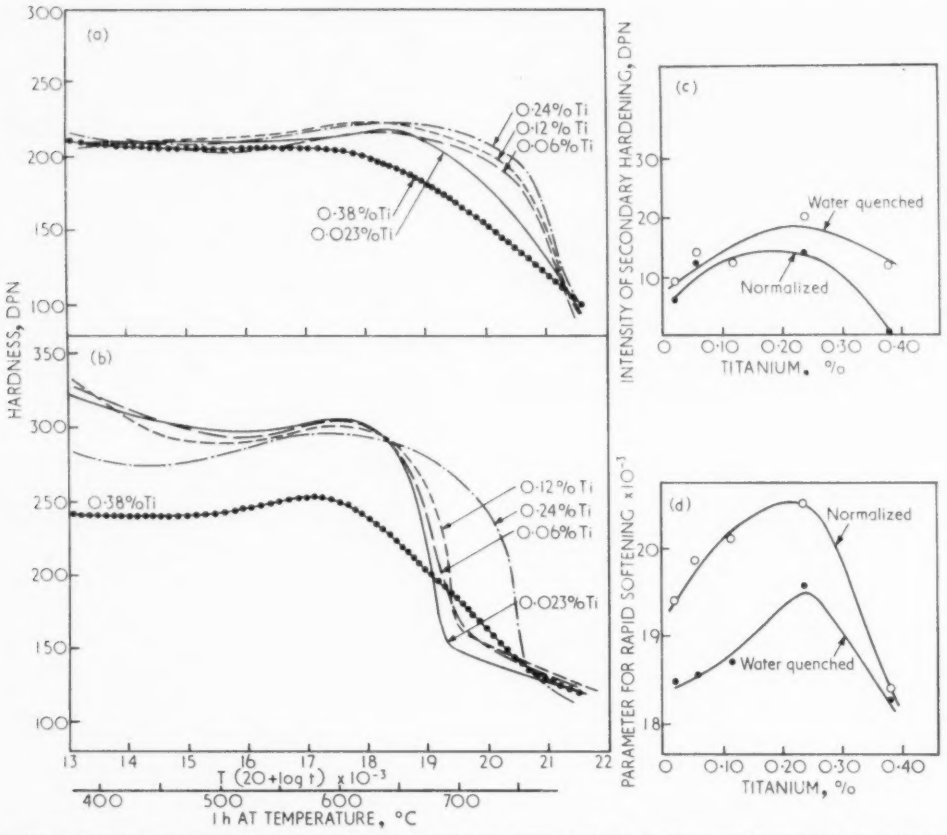
tion relationships given by Smith and Nutting[9] for V_4C_3 and α-Fe, it can be shown qualitatively that the degree of misfit increases with increasing vanadium content. This increases the coherency strains and hence the secondary hardening until the misfit becomes so large that coherency is lost, when the secondary hardening decreases.

Titanium

It is known that titanium can produce secondary hardening and the effect of small titanium additions is interesting because this element is frequently used in small amounts to fix the nitrogen prior to boron additions. Titanium additions up to 0·38% were used and the tempering curves are shown in Fig.13. It will be seen that titanium reduces the hardness in the water-quenched condition, due to reaction with carbon which lowers the carbon content of the martensite. There is little effect on the bainitic structure, which shows that the hardness of this structure results mainly from the fine grain size. Titanium introduces slight secondary hardening during tempering and this effect would probably be increased if a higher solution temperature was used to obtain more effective solution of TiC. The secondary hardening effect depends very much on the titanium content and is most evident between 0·1% and 0·3%Ti. This effect is summarized in Fig.13*c* and *d* and it will be seen, in fact, that the 0·38%Ti steel softens more rapidly than the 0·023%Ti steel. Once again the secondary hardening process occurs more rapidly in the water-quenched condition. The tempering parameters at which maximum secondary hardening is produced are similar to those indicated for vanadium. The most effective titanium content is 0·21–0·24% which is equivalent to a TiC ratio of 3:1.

Chromium

Chromium is a useful element in producing high-strength bainitic steels and it was therefore decided to investigate the effect of up to 4%Cr on the tempering characteristics. Chromium has quite a marked effect in raising the initial hardness level in both the martensitic and bainitic conditions. The tempering curves are shown in Fig.14 and the main effects can be summarized quite briefly. The hardness level at low tempering parameters mainly reflects the increasing initial hardness level with increasing chromium content, but it can be seen that increasing chromium tends to retard softening in part of the tempering process. Apart from the ½%Cr steel there is no secondary hardening effect



13 *The effect of titanium on tempering characteristics* (a) *hard ness, normalized,* (b) *hardness, water quenched,* (c) *effect on intensity of secondary hardening,* (d) *effect on the parameter for rapid softening*

at higher tempering parameters to retard the softening and it will be seen that the tempering parameter at which major softening occurs decreases with increasing chromium content, and the softening becomes more rapid (Fig.14*c*). At high tempering parameters the hardness increases with increasing chromium content, presumably due to solid solution hardening. This produces a double crossover in the tempering curves which makes interpretation difficult. They have therefore been re-drawn for the bainitic steels in Fig.14 using a common origin and it will be seen that the effect of increasing chromium content in accelerating the rate of softening is clearly shown.

In the $\frac{1}{2}$%Cr steel the chromium addition accentuates the hardening effect due to the $\frac{1}{2}$%Mo present, presumably by dissolving in the Mo_2C. Electron microscope examination shows that a needle-like precipitate is formed (Fig.15*a*). Above 1%Cr, however, Mo_2C no longer forms and Cr_7C_3 is formed instead and this forms by separate nucleation as small plates in the matrix (Fig.15*b*). Seal and Honeycombe[12] and Pickering[13] found similar modes of formation of Cr_7C_3 in high chromium steels. At the same time there is transformation of any previously existing Fe_3C to Cr_7C_3 *in situ* (Fig.15*c*). The reason why the Cr_7C_3 precipitate produces no secondary hardening must be that coherency straining is slight or rapidly lost. During continued tempering, the Cr_7C_3 particles grow into small slabs (Fig.15*d*) which finally grow into large particles at the highest parameters (Fig.15*e*). During this stage of tempering the Cr_7C_3 particles transform to $M_{23}C_6$ in the higher-chromium steels.

The most important feature of these chromium steels is the low tempering parameter at which softening occurs. This means that if chromium displaces either molybdenum or vanadium as the carbide-forming element, the tempering resistance will be very much decreased.

Manganese

Manganese is also a useful element for producing high-strength bainitic steels and therefore the effect of manganese additions of up to 4% has been examined. The tempering curves are shown in Fig.16 and it will be seen that these are very much affected by manganese increasing the initial hardness level. There is no secondary hardening reaction to retard the softening during tempering and it appears that increasing manganese accelerates the softening reaction. In these steels there is little difference in the rate of softening of the bainitic and martensitic structures.

Nickel

The effect of nickel additions up to 4% was examined and the tempering curves are shown in Fig.17. The initial hardness levels are increased by increasing nickel and this hardness difference is maintained at

low tempering parameters. There is no secondary hardening to retard the softening and it appears that increasing nickel accelerates the softening process (Fig.16). This effect is more clearly shown when the tempering curves are re-drawn from the same origin. The martensitic steels soften at lower tempering parameters than the bainitic steels. It will be realized that manganese and nickel, in accelerating the softening process, may be an indirect effect, related more to the nature of the initial structure. This point is discussed later.

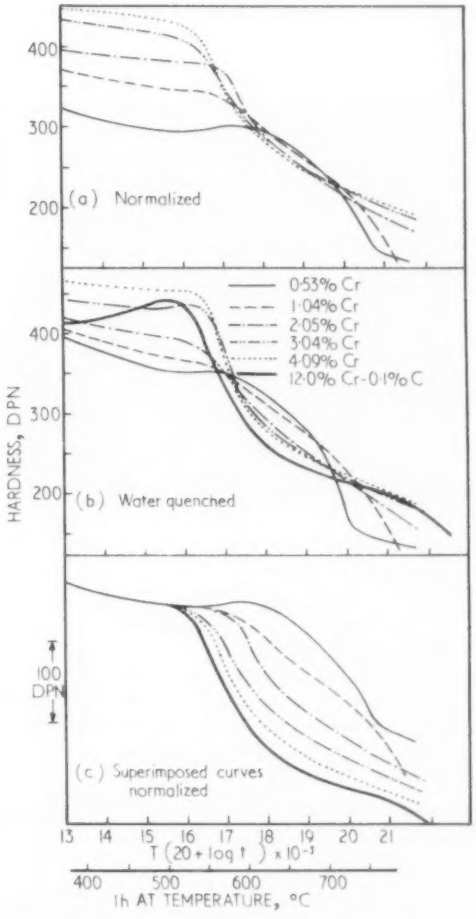
Carbon

A major feature of the high-strength bainitic steels described in this paper is that the carbon content is low to provide the best associated properties of ductility and weldability. It is useful however, to know the effect of carbon on the tempering characteristics, and this has been investigated in both ageing and non-ageing compositions. A 2%Mo–B base composition was used for the ageing steel. The tempering curves are shown in Fig.18*a* and it will be seen that the effect of carbon in raising the initial hardness level is maintained during tempering so that the higher-carbon steels have a higher hardness at all tempering temperatures up to 750°C. However, it will be seen that increasing carbon does not alter any of the tempering reactions, because the tempering curves have the same general shape, and where secondary hardening occurs, it does so at very much the same tempering parameter and to much the same extent. In the non-ageing steel increasing carbon appears to accelerate the softening reaction, although this may be due to the effect of initial structure (Fig.18*b*).

THE EFFECT ON INCREASING INITIAL TENSILE STRENGTH LEVEL

In the steels so far examined it has been shown that single additions of alloying elements result in increased initial hardness and this initial hardness difference is reflected throughout the tempering curve. It has also been shown that secondary hardening processes are affected by the initial structure or hardness level. It is not easy to assess this effect, however, when the single alloying addition is affecting both the initial hardness level and the secondary hardening process. It is possible to assess this more accurately if different initial hardnesses are obtained by alloy additions which play no part in the secondary hardening reaction. Manganese and chromium are two elements which are very effective in altering the initial bainitic hardness level (and to a much smaller extent the initial martensitic hardness level). It is possible therefore, to use three separate base compositions, ½%Mn–½%Mo–B, 1%Mn–1%Cr–½%Mo–B, and 1½%Mn–1½%Cr–½%Mo–B to which various additions of molybdenum and vanadium can be made. It will be realized that from these steels a large number of tempering curves can be obtained which cannot conveniently be illustrated. One representative sample is given in Fig.19 which shows the typical result obtained. This shows the effect of adding 2%Mo (which is known will give marked secondary hardening) to the three base compositions, starting from both the bainitic and martensitic conditions. The two most important features of these steels are the degree of secondary hardening and the tempering parameter at which this secondary hardening occurs. It will be seen that with increasing initial hardness the amount of secondary hardening is decreased and the process is also accelerated because the peak secondary hardening occurs at a lower tempering parameter. The separate effects of molybdenum and vanadium are summarized in Figs.19*c* and *d* and while these elements have the same effect as described previously, the effect of initial hardness level is also clearly shown. Molybdenum in increasing amounts up to 3% produces increasing secondary hardening, while vanadium has an optimum effect at 0·4%. The amount of secondary hardening in all these steels decreases as the initial hardness level increases. Consequently, secondary hardening is also less in the martensitic condition than in the bainitic condition.

While it has been stated that it is the initial hardness level which is affecting the secondary hardening, it will be appreciated that the manganese and chromium content may also be affecting this. In fact there is evidence of this in the water-quenched condition, where the initial hardness is only slightly altered but

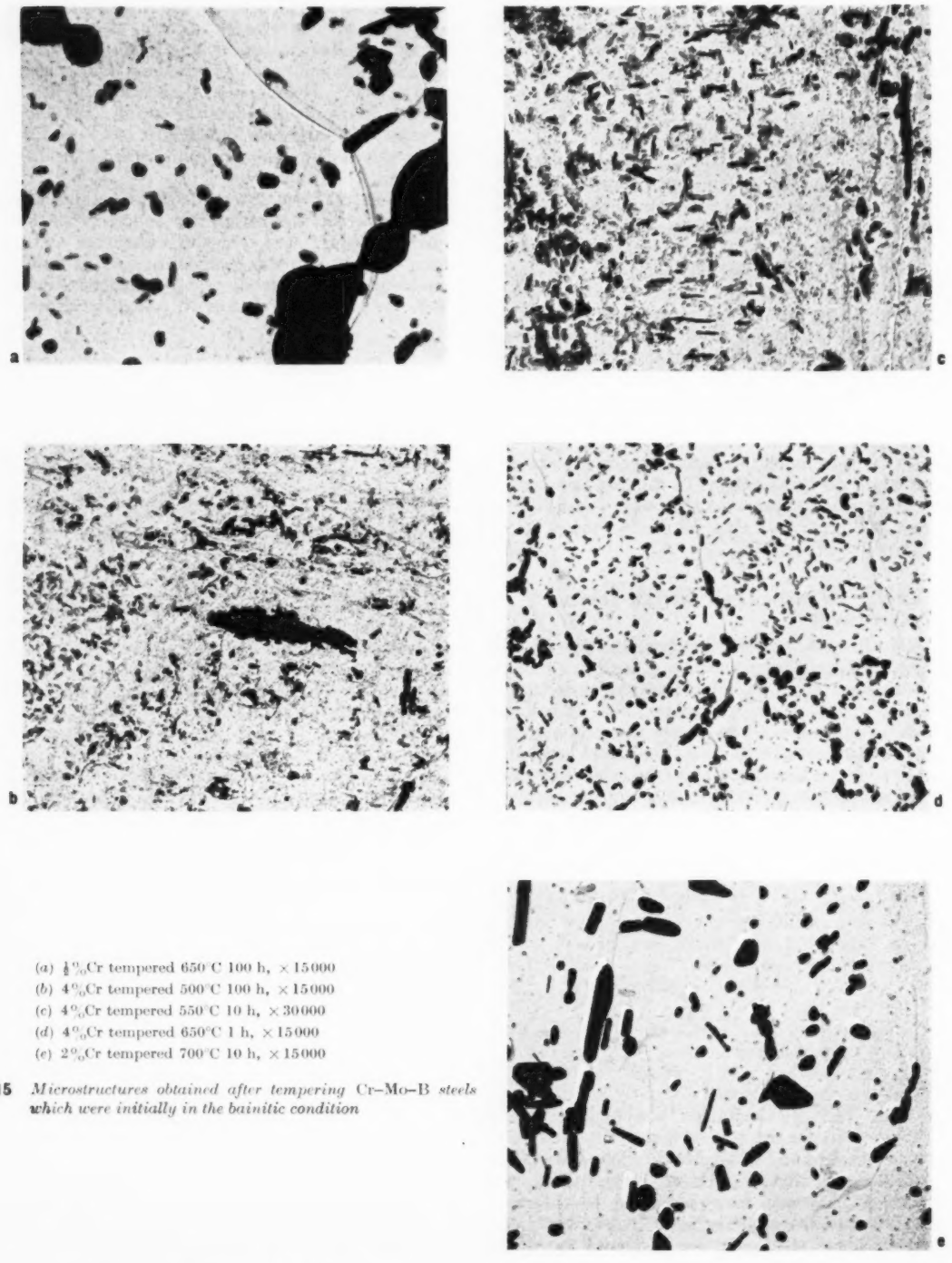


14 *The effect of chromium on the tempering characteristics* (a) *hardness, normalized,* (b) *hardness, water quenched,* (c) *hardness, superimposed curves, normalized*

the secondary hardening is decreased by increasing manganese and chromium. It is very difficult to separate these two effects, but it does seem clear that both the initial structure and the alloy content can affect the amount of secondary hardening.

THE EFFECT OF COLD WORK

It has been shown how initial hardness level affects the tempering characteristics of these steels and cold work is one way in which the initial hardness level can be raised. It is also known that cold work accelerates



(*a*) $\frac{1}{2}$%Cr tempered 650°C 100 h, ×15000
(*b*) 4%Cr tempered 500°C 100 h, ×15000
(*c*) 4%Cr tempered 550°C 10 h, ×30000
(*d*) 4%Cr tempered 650°C 1 h, ×15000
(*e*) 2%Cr tempered 700°C 10 h, ×15000

15 *Microstructures obtained after tempering* Cr–Mo–B *steels which were initially in the bainitic condition*

age-hardening reactions. It would be expected, therefore, that cold work would accelerate the softening of these low-alloy steels during tempering. This affect possibly has some commercial significance and therefore it was decided to investigate the effect of cold work on the tempering characteristics of the $\frac{1}{2}$%Mo–B base composition steel. Specimens of this steel were cold rolled up to 90% reduction and subsequently the tempering characteristics were determined. The general effect of cold work is shown in Fig.20. It will be noticed that increasing cold work considerably raises the initial hardness level before tempering. Apart from this however, the major effect of cold work is on the softening reaction. Both the slight ageing reaction and the subsequent softening occur more quickly as the degree of cold work increases. It was shown previously that the rate of softening in the normalized material was controlled by the precipitation and overageing of Mo_2C and it is this process which is accelerated by cold work. The increase in the rate of overageing of Mo_2C allows recrystallization and grain growth to occur more rapidly and hence produces more rapid softening. Similar effects would be obtained on any of the other steels which have been described in earlier sections of this paper.

DISCUSSION OF TEMPERING CHARACTERISTICS

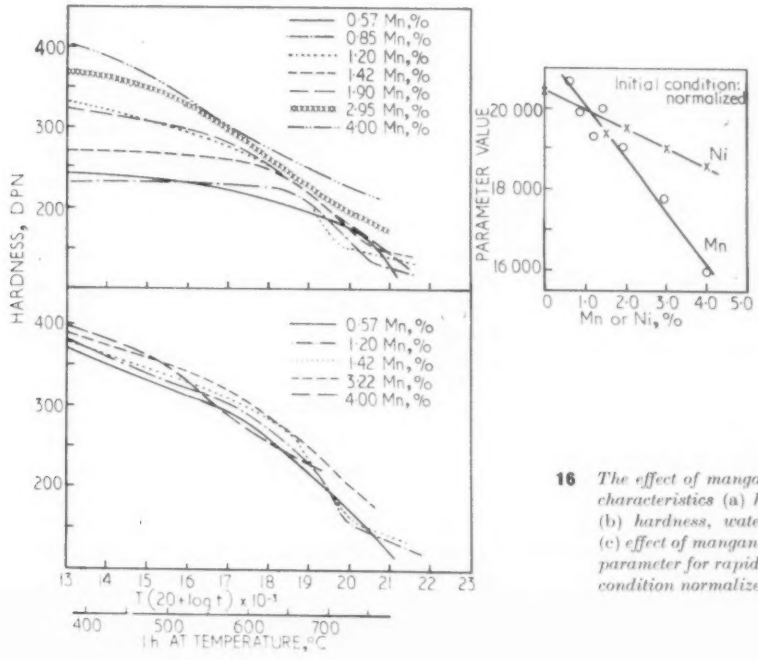
While very many results have been presented, there are only a few major effects and these can be discussed briefly. A clear distinction can be drawn between the effects of elements like manganese and nickel and those which produce marked secondary hardening like molybdenum, tungsten, vanadium, and titanium. Chromium is intermediate in its effect because while it produces a separately nucleated carbide, the secondary hardening effect is negligible.

It is useful to summarize the tempering mechanism of these steels which it will be remembered all contain at least $\frac{1}{2}$%Mo to enable bainitic structures to be produced. The basic change on tempering is that any Fe_3C present in the initial microstructure is dissolved and a fine matrix precipitate of Mo_2C is formed. In the bainitic structures, the Fe_3C occurs as relatively large bainitic carbide aggregates, while in the martensitic structures the Fe_3C occurs as very small particles which are formed either during cooling from the relatively high M_S or during subsequent re-heating.

Since the rate of solution of the Fe_3C controls the subsequent formation of alloy carbides, this is why the initial structure has such a marked effect on the rate of secondary hardening and softening. The smaller carbides in the martensitic structure dissolve more rapidly than the larger bainitic carbides and consequently secondary hardening occurs more rapidly in the martensitic structure. Also the carbide particle size in bainitic structures decreases as the initial hardness level increases and this results in more rapid solution and accelerated secondary hardening.

At this present stage of the work it is not possible to assess the direct effect of manganese or nickel accurately nor to provide an explanation. The effect of the secondary hardening elements is easier to explain. Since the base steel contains $\frac{1}{2}$%Mo, increasing amounts of molybdenum increase the amount of the matrix precipitate and increase the amount of secondary hardening. If, instead, tungsten or vanadium are present, then the matrix precipitate changes to W_2C or V_4C_3 but in either case secondary hardening occurs. These secondary hardening reactions are also accelerated by an increasing hardness level of the initial structure, which implies a finer carbide particle size and hence more rapid solution.

From these results it is possible to see how the compositions for bainitic steels are selected. An appro-

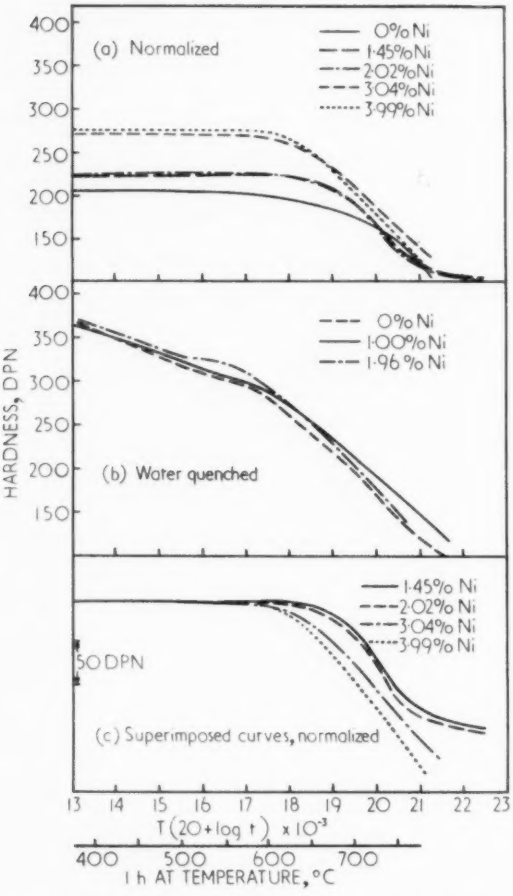


16 *The effect of manganese on tempering characteristics* (a) *hardness, normalized,* (b) *hardness, water quenched,* (c) *effect of manganese and nickel on the parameter for rapid softening, initial condition normalized*

priate combination of manganese, chromium, or nickel is selected to give the required initial strength level and then the necessary tempering resistance can be obtained by an appropriate addition of molybdenum, tungsten, or vanadium. In martensitic steels a rather different situation exists because here a primary requirement from the alloy composition is adequate hardenability. Very similar conditions apply to the use of molybdenum or vanadium for tempering resistance, however.

THE EFFECT OF TEMPERING ON MECHANICAL PROPERTIES

Attention has been confined to bainitic structures when considering the effect of tempering on mechanical properties. In general, the tensile strength of tempered bainitic steels closely follows the hardness curves. However, it has been seen that during tempering, a precipitate of Mo_2C is formed and this stage of tempering produces an improved combination of mechanical properties since the proof stress/tensile strength ratio is improved. This is shown for a high-strength bainitic steel in Fig.21*a*. This steel has a 0·1%C–½%Mo–B base composition with 1½%Mn–1½%Cr additions and this does not show strong secondary hardening. In this steel quite good mechanical properties are obtained up to a tempering temperature of 550°C above which the tensile strength decreases quite sharply. It is possible to add pronounced secondary hardening to this steel either by increasing the molybdenum content to 2% or by adding 0·3%V. The tensile properties obtained on tempering a 0·3%V steel are shown in Fig.21*b* and the beneficial effect of secondary hardening can be clearly seen. Good tempering resistance is now obtained up to 650°C.



17 *The effect of nickel on tempering characteristics,* (a) *hardness, normalized,* (b) *hardness, water quenched,* (c) *hardness, superimposed curves, normalized*

From these results it is clear that the microstructure which results from a combination of the fine initial structure of a low-temperature bainite transformation and the fine matrix precipitate from a secondary hardening reaction has very satisfactory room-temperature properties. It can be shown that it also has attractive high-temperature properties. Tensile properties were determined up to 500°C and these results are given in Tables II and III. Perhaps the most important property is the 0·2% PS and these values are summarized in Fig.22 for two steels with and without 0·3%V.

There are two important features of these results. In the vanadium-free steel it will be seen that the lower tempering temperatures give the best high-temperature strength because it is these tempering temperatures which produce a fine matrix precipitate and give higher initial strength. On the other hand, with the vanadium steel it is the 550° and 600°C tempering treatments which produce the highest strength because these tempering treatments produce the optimum size for the fine matrix precipitate of V_4C_3. The combination of the high initial strength and the fine matrix precipitate produces superior high temperature strength at the tempering temperatures.

Increasing use is likely to be made of bainitic steels and it is therefore interesting to see the effect of the different alloying elements on the tempering characteristics and the combined effect of tempering characteristics and alloying elements on the mechanical properties which can be obtained.

ACKNOWLEDGMENTS

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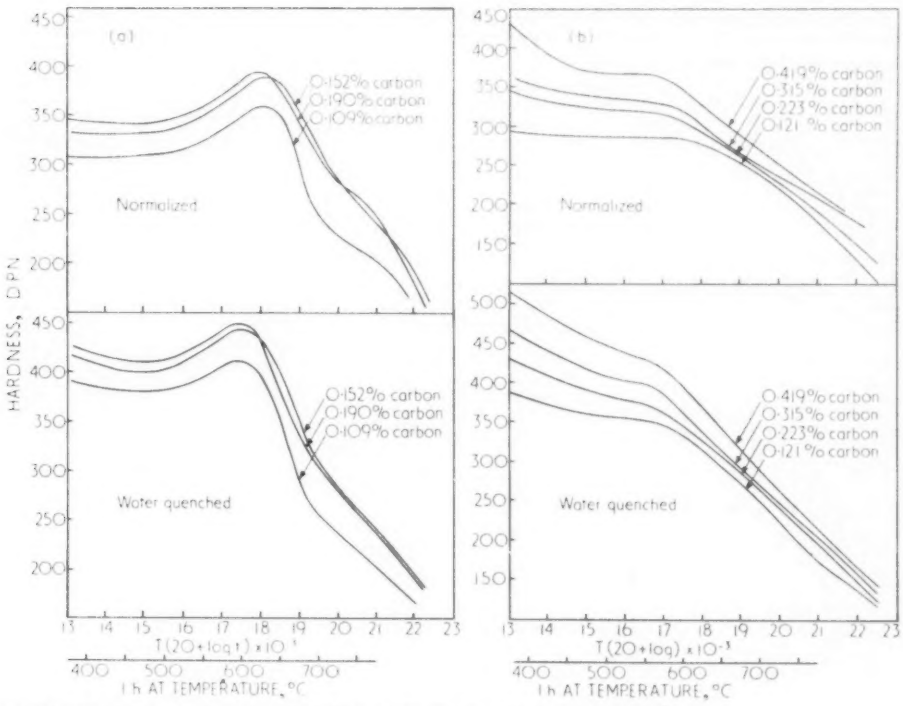
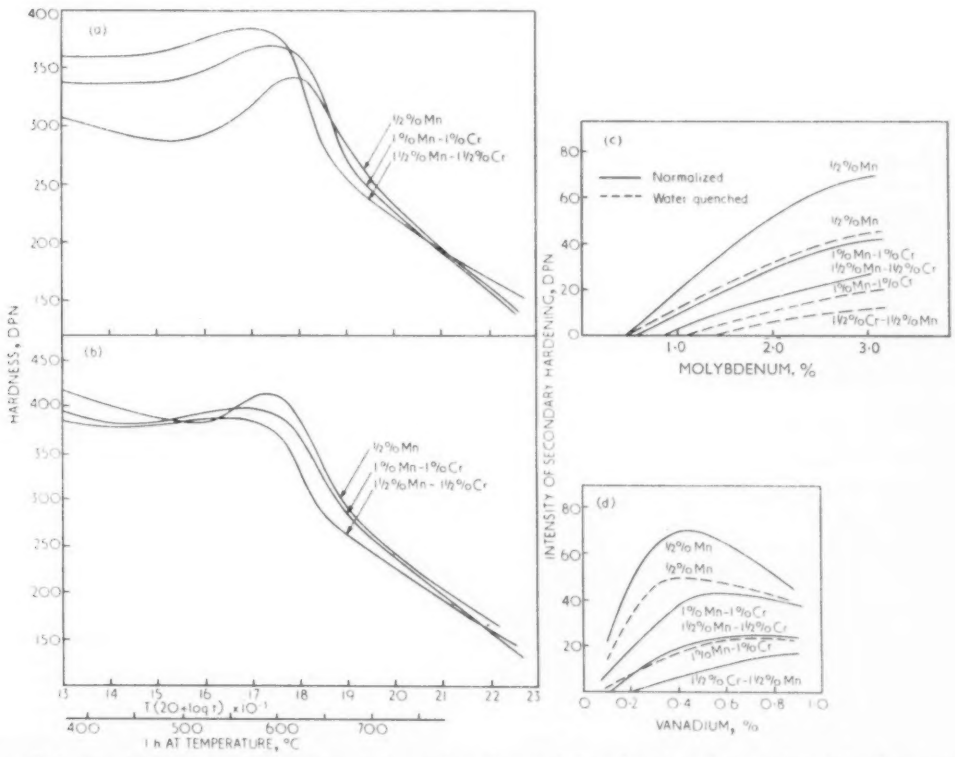
References on page 153



18 *The effect of carbon on tempering characteristics* (a) *2%Mo steels*, (b) *1%Cr–½%Mo steels*



19 *The effect of molybdenum and vanadium on tempering characteristics of various base steels* (a) *hardness, normalized*, (b) *hardness, water quenched*, (c) *effect of* Mo *on intensity of secondary hardening*, (d) *effect of vanadium on intensity of secondary hardening*

TABLE II Mechanical properties of a 1½%Mn–1½%Cr–½%Mo–B steel

Effect of tempering on room temperature properties						
Tempering treatment	Normalized	450°C, 1 h	500°C, 1 h	550°C, 1 h	600°C, 1 h	650°C, 1 h
Tensile strength, tons/in²	62·1	66·9	66·7	66·0	56·0	51·4
0·2% PS, tons/in²	45·3	51·6	49·0	50·2	47·3	40·0 YP
0·1% PS, tons/in²	38·4	47·4	45·3	45·8	45·8	40·0 YP
0·05% PS, tons/in²	32·0	43·6	41·8	41·6	43·8	40·0 YP
0·02% PS, tons/in²	25·6	39·5	38·0	36·4	40·3	40·0 YP
Elongation on $4\sqrt{A}$, %	18·6	23·9	23·9	22·6	25·0	22·9
Reduction in area, %	55·3	62·4	62·4	60·8	67·2	72·0
Ratio 0·20% PS/TS	0·73	0·77	0·73	0·76	0·84	0·78

Effect of test temperature on properties after tempering 450°C, 1 h						
Test temperature, °C	20	200	300	420	500	600
Tensile strength, tons/in²	66·9	68·7	72·4	61·9	54·2	32·6
0·2% PS, tons/in²	51·6	50·3	50·2	44·8	35·8	28·0
0·1% PS, tons/in²	47·4	44·7	45·4	38·2	30·6	24·9
0·05% PS, tons/in²	43·6	40·2	40·6	33·0	25·3	22·0
0·02% PS, tons/in²	39·5	35·7	37·0	28·7	19·6	18·8
Elongation on $4\sqrt{A}$, %	23·9	16·8	20·2	23·2	23·2	26·6
Reduction in area, %	62·4	41·6	47·2	64·0	65·6	70·8
Ratio 0·20% PS/TS	0·77	0·73	0·69	0·73	0·66	0·86

Effect of test temperature on properties after tempering 650°C, 1 h					
Test temperature, °C	20	200	300	400	500
Tensile strength, tons/in²	51·4	42·8	43·5	41·2	34·4
0·2% PS, tons/in²	40·0 YP	37·0 YP	36·6	33·6	29·6
0·1% PS, tons/in²	40·0 YP	37·0 YP	35·7	32·5	28·0
0·05% PS, tons/in²	40·0 YP	37·0 YP	35·0	31·2	25·9
0·02% PS, tons/in²	40·0 YP	37·0 YP	33·8	29·4	22·8
Elongation on $4\sqrt{A}$, %	22·9	22·3	20·3	27·0	31·4
Reduction in area, %	72·0	67·7	67·6	62·9	72·0
Ratio 0·2% PS/TS	0·78	0·86	0·84	0·82	0·86

Analysis 0·09%C–1·70%Mn–1·51%Cr–0·54%Mo–0·0030%B

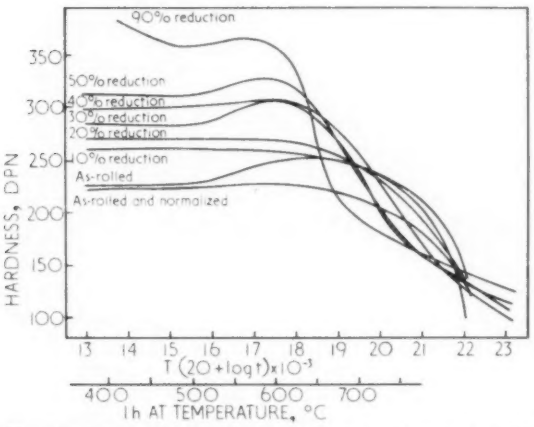
TABLE III Mechanical properties of a 1½%Mn–1½%Cr–½%Mo–V–B steel

Effect of tempering on room temperature properties					
Tempering treatment	450°C, 1 h	500°C, 1 h	550°C, 1 h	600°C, 1 h	650°C, 1 h
Tensile strength, tons/in²	75·2	76·9	77·4	75·3	65·1
0·2% PS, tons/in²	55·6	53·8	55·0	65·0	60·5
0·1% PS, tons/in²	51·4	48·0	48·8	60·2	59·0
0·05% PS, tons/in²	47·4	42·6	42·9	54·0	57·2
0·02% PS, tons/in²	43·0	37·6	35·8	43·0	53·7
Elongation on $4\sqrt{A}$, %	20·5	22·6	22·1	23·6	24·0
Reduction in area, %	56·0	57·6	60·8	ND	65·6
Ratio 0·2% PS/TS	0·74	0·70	0·71	0·86	0·93

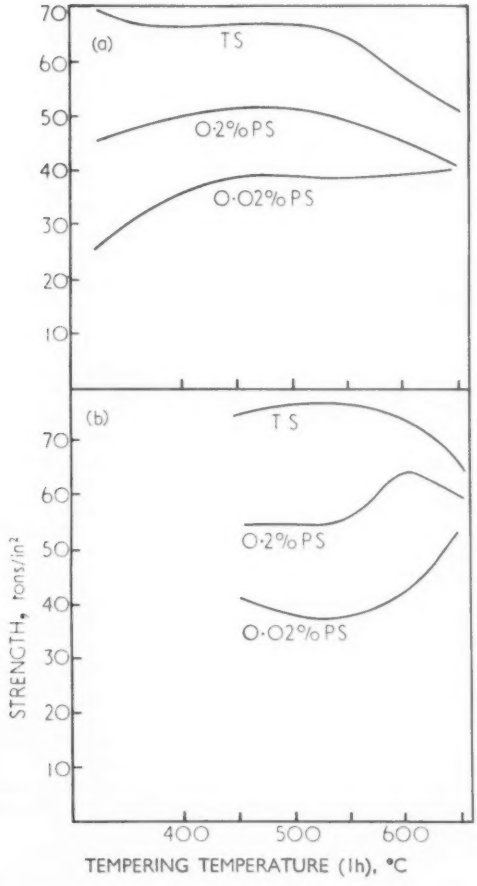
Effect of test temperature on properties after tempering 450°C, 1 h						
Test temperature, °C	20	200	300	400	500	600
Tensile strength, tons/in²	75·2	71·3	78·2	72·2	62·5	44·4
0·2% PS, tons/in²	55·6	53·6	53·8	50·7	45·8	32·2
0·1% PS, tons/in²	51·4	49·0	48·0	44·0	39·0	27·9
0·05% PS, tons/in²	47·4	45·0	42·0	38·0	33·0	22·6
0·02% PS, tons/in²	43·0	39·6	36·8	32·2	26·8	16·6
Elongation on $4\sqrt{A}$, %	20·5	18·7	19·6	20·9	24·2	22·8
Reduction in area, %	56·0	57·6	43·2	57·2	62·4	43·2
Ratio 0·2% PS/TS	0·74	0·75	0·69	0·70	0·73	0·73

Effect of test temperature on properties after tempering 650°C, 1 h						
Test temperature, °C	20	200	300	400	500	600
Tensile strength, tons/in²	65·1	60·8	59·0	55·5	49·1	36·6
0·2% PS, tons/in²	60·5	54·8	54·0	49·6	41·6	27·5
0·1% PS, tons/in²	59·0	52·8	51·8	46·0	39·0	24·1
0·05% PS, tons/in²	57·2	49·2	50·0	43·2	35·6	20·2
0·02% PS, tons/in²	53·7	45·6	45·4	39·2	30·4	16·1
Elongation on $4\sqrt{A}$, %	24·0	20·2	18·6	25·7	28·6	25·0
Reduction in area, %	65·6	60·0	60·8	65·6	64·0	54·4
Ratio 0·2% PS/TS	0·93	0·90	0·92	0·89	0·85	0·75

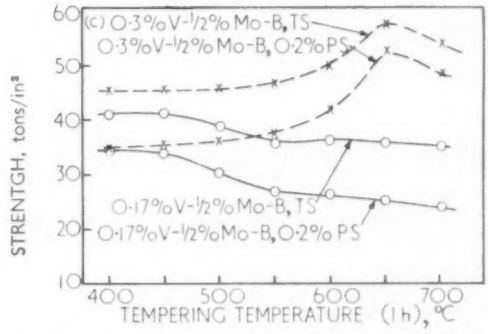
Analysis 0·09%C–1·51%Mn–1·57%Cr–0·52%Mo–0·39%V–0·0032%Sol.B.



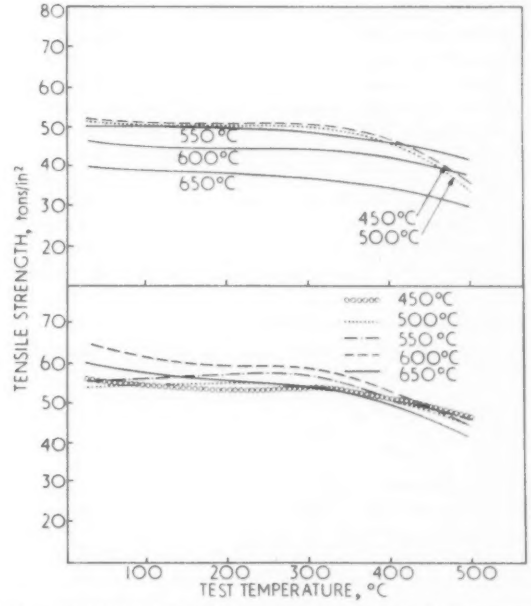
20 *The effect of cold work on the tempering characteristics of* ½%Mo–B *steel*



21 *The effect of tempering temperature on the tensile strength* **a,b** *of steels with and without vanadium* (a) 1½%Mn–1½%Cr–½%Mo–B *steel*, (b) 1½%Mn–1½%Cr–½%Mo–0·3%V–B *steel*



21c *The effect of varying vanadium content on* ½%Mo–B *steel*



22 *The effect of tempering temperature on the high temperature 0·2% proof stress values of steels with and without vanadium*

REFERENCES

1. E. C. Bain: 'Functions of the alloying elements in steel', 1939, Cleveland, ASM.
2. W. Crafts and J. L. Lamont: *Trans. AIME*, 1950, **188,** 561–574.
3. K. J. Irvine *et al.*: *JISI*, 1957, **186,** 54–67.
4. K. J. Irvine and F. B. Pickering: *ibid.*, **187,** 292–309.
5. K. J. Irvine and F. B, Pickering: *ibid.*, 1958, **188,** 101–112.
6. R. H. Aborn: *Trans. ASM*, 1956, **48,** 51–83.
7. C. C. Busby, M. F. Hawkes, and H. W. Paxton: *Trans. ASM*, 1955, **47,** 135–153.
8. J. H. Holloman and L. D. Jaffe: *Trans. AIME*, 1945, **162,** 223–249.
9. E. Smith and J. Nutting: *JISI*, 1957, **187,** 314–329.
10. K. Kuo: *ibid.*, 1953, **173,** 363–375.
11. H. Krainer: *Arch. Eisenhüt.*, 1950, **21,** 39–41.
12. A. K. Seal and R. W. K. Honeycombe: *JISI*, 1958, **188,** 9–15.
13. F. B. Pickering: 'Conference on precipitation processes in steels', 1958, Sheffield (in the press).
14. A. K. Seal and R. W. K. Honeycombe: *JISI*, 1958, **188,** 343–350.

Some changes in the mechanical properties of mild steel caused by fatigue stressing

G. F. Modlen, M.A., Ph.D., and G. C. Smith, M.A.

SYNOPSIS

Changes in the stress/strain curve and hardness have been followed during the fatigue of strain-aged mild steel. Initially the hardness falls, and if the specimen temperature does not rise, the hardness continues to fall until fracture. If the specimen is allowed to become hot, the hardness increases over a comparatively short number of cycles, and then remains roughly constant until fracture occurs. A tentative dislocation model is advanced to explain these results. 1689

INTRODUCTION

THERE IS MUCH EVIDENCE in the literature that anomalous effects may be observed during the repeated stressing of steels. Prolonged fatigue stressing below the yield point may produce plastic flow, and eventually fracture. This implies that the yield stress, as measured in tension, is lowered by the repeated stressing, and this has been observed.[1–5]

In the experiments to be described hardness changes taking place during the fatigue of strain-aged mild steel have been followed, and these have been correlated with changes in hysteresis and in tensile properties.

EXPERIMENTAL PROCEDURE

The analysis of the steel used is given in the table below:

Element, wt-%					
C	Si	Mn	S	P	N_2
0·17	0·028	0·62	0·048	0·20	0·004

The as-received hardness was 190 DPN due to work hardening and also strain ageing since several months had elapsed between the work hardening and testing. Normalizing for 30 min at 950°C resulted in a hardness of 115 DPN. Push-pull fatigue testing was carried out using a 6-ton Losenhausen pulsator, the specimen of Fig.1 being used. In this machine, a spring applies a constant tensile load to the specimen, and this is countered by a fluctuating compression load. By adjustment, the required load range is obtained. The same machine was used for pre-straining, and also for the determination of the initial parts of the load/elongation diagrams, the extension of the whole specimen between the grips being measured with a dial gauge.

The specimens were polished to 0000s emery longitudinally before test: after pre-straining, no further surface treatment was in general carried out. Strain ageing was by immersion in an oil bath for 8 min at 150°C, followed by degreasing before testing.

For hardness measurements, impressions were made on the specimen surface, using a 30-kg load. Provided the indentor was vertically above the axis of the specimen, the impressions were not much distorted, and consistent results could be obtained. The temperature of the specimen during test could be measured by a chromel/alumel thermocouple spring loaded on to the surface.

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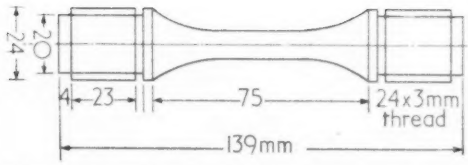
EXPERIMENTAL RESULTS

Strain-aged specimens: changes in hardness and temperature

The hardness and temperature changes observed in as-received specimens are shown in Figs.2–5. The temperatures recorded are those for specimens run to fracture without interruption: for hardness testing another specimen was used and removed from the machine at intervals during the fatigue test. In fact this procedure makes a negligible contribution to the temperature attained by a specimen, for upon retesting the temperature soon returns to the value typical of the uninterrupted test. It is seen that similar curves are obtained at the different stress levels, the temperature of the specimen showing a rather sudden increase to a plateau at the same time as the hardness increases. At the same time that the increase in temperature, and therefore in cyclic plastic deformation, takes place, a corresponding increase is observed in the number and intensity of slip lines on the specimen surface (Fig.6 *a–d*). At low stresses, fracture occurs before the temperature attains its plateau value, and the hardness decreases steadily throughout the test.

In Fig.7 are shown the S/N curves at various hardness levels, together with the points of inflexion on the temperature/N curves.

The hardness decrease observed at the beginning of the test is small, but was found in all the specimens tested and must be regarded as genuine. If the specimen was tested at a sufficiently low speed to avoid heating, or was cooled with an air blower during the test, the final increase in hardness did not take place. Instead the hardness of the specimen continued to fall



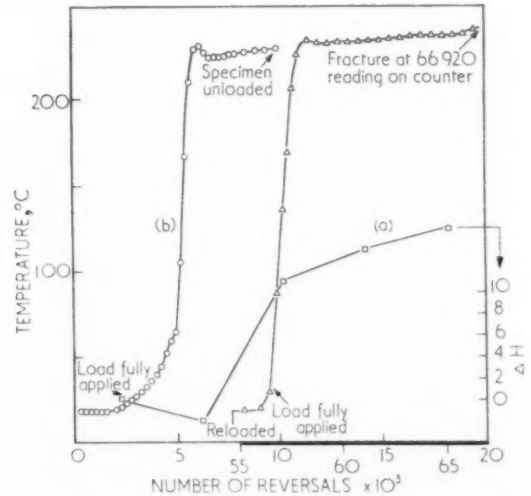
1 *Diagram of specimen tested in 6-ton Losenhausen machine*

until fracture occurred (Table I). In the same way, if the specimen temperature increased during test the hardness was not uniform but varied along the test section in the same way as the temperature had done during test (Fig.8).

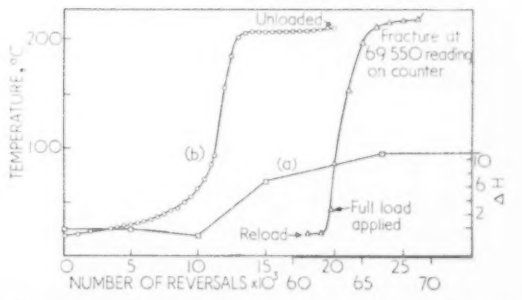
These changes in hardness are reflected in the stress/strain curve. In Fig.9 are shown the stress/strain curves after various treatments: it is clear that the marked yield point resulting from strain ageing is modified by the repeated stressing and that the later part of the curve is little affected unless the specimen temperature rises. This accounts for the decrease in hardness observed throughout the fatigue life of specimens which did not show a temperature rise. If the specimen temperature increased during test, the yield point is not raised, but the later parts of the curve are. Hence an increase in indentation hardness is observed.

Figure 10 shows that when the yield point has been lowered by fatigue it cannot be raised by ageing to the value obtaining before test, but that the extent of the elastic range may be considerably increased. More prolonged ageing is required to bring this about if the specimen temperature is allowed to increase during test.

It seems that strain ageing is unable to produce a yield point, when testing is not continued in the same sense as the prior deformation,[6] or if the prior deformation has not been unidirectional. This second point was demonstrated by deforming a specimen in tension and then compressing it to zero residual strain. After ageing 8 min at 150°C, subsequent tensile testing did not reveal a yield point (Fig.11).



2 *Changes in hardness and temperature caused by fatigue testing an as-received specimen at ±21 tons/in²*



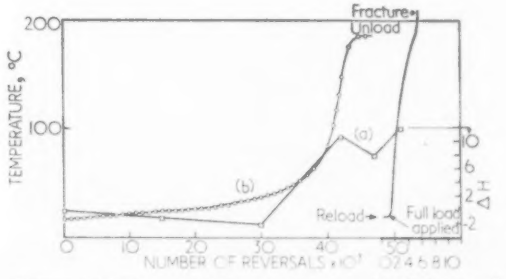
3 *Changes in hardness and temperature caused by fatigue testing an as-received specimen at ±20 tons/in²*

Changes in mechanical hysteresis

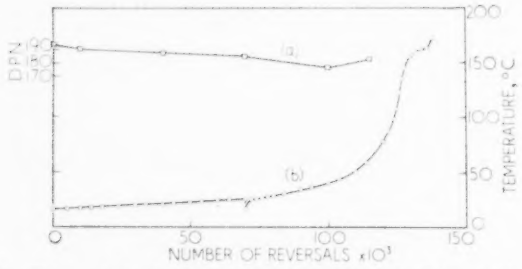
The changes in specimen temperature are due to corresponding changes in the energy dissipated in each cycle by mechanical hysteresis. Hysteresis loops for specimens could be mapped out at low speeds by manual control of the machine, the strains being measured by means of a dial gauge, as for the load-extension curves. The loop areas were measured at room temperature and it was found that changes in specimen temperature and in loop area could be correlated as shown in Fig.12.

It is known that the damping capacity of mild steel increases during fatigue testing, and that rest periods are effective in decreasing this damping.[7] Experiments designed to throw some light on the kinetics of this change in energy dissipation were therefore performed.

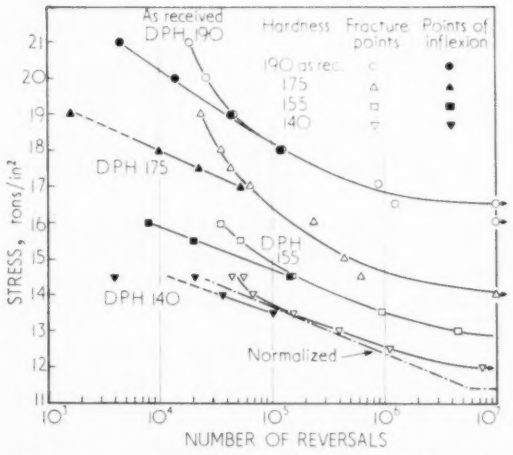
A normalized specimen was strain aged to a hardness of 155 DPN, and cooled during fatigue testing at ±15·5 tons/in² for 20000 cycles. The loop width was measured by applying the same extreme loads as had been used during the fatigue test. When the loop width had been measured after each ageing treatment the specimen was refatigued so that the loop returned to its initial size. This procedure was adopted because preliminary experiments had shown that after ageing, the actual process of measuring loop width caused a progressive increase in the loop area. From the results shown in Fig.13 an approximate activation energy for the process of some 25 kcal can be derived. Some early experiments with as-received specimens had indicated that more prolonged ageing was necessary to reduce the size of the hysteresis loop, the higher the temperature attained during the test. This effect was verified, making use of a strain-aged specimen, as is shown in Table II.



4 *Changes in hardness and temperature caused by fatigue testing an as-received specimen at ±19 tons/in²*



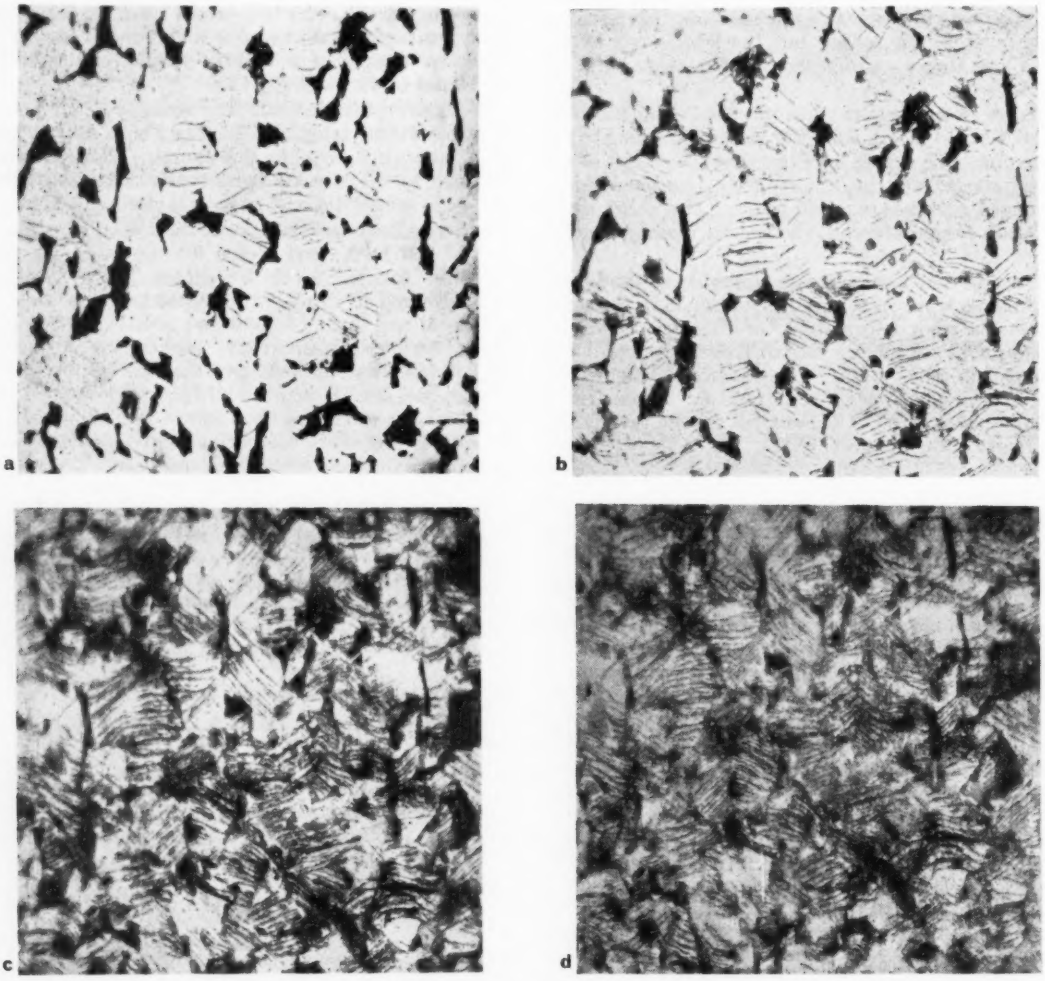
5 *Changes in hardness and temperature caused by fatigue testing an as-received specimen at ±18 tons/in²*



7 *S/N curves for mild steel after strain ageing to various hardness levels. Also shown are the points of inflexion on the curves of specimen temperature as a function of number of cycles*

Normalized, and normalized and freshly strained specimens

The curves of specimen temperature against number of cycles for unstrained specimens fall into two groups.[8] If the yield point is exceeded, a rapid increase in temperature occurs at the beginning of test, followed by a fall to a value which gradually rises until fracture occurs. If the applied stress is below the yield



(*a*) 5000 cycles (*b*) 9000 cycles (*c*) 13500 cycles (*d*) 19000 cycles

6 *Surface deformation resulting from fatigue testing an as-received specimen at ±21 tons/in²* ×250

TABLE I As-received specimen

Machine speed, cycles/min	Max. temperature, °C	Stress, tons/in²	No. of cycles	Hardness, DPN
1000	210	±20	0	188
			10000	187
			15000	195
			23500	199
			26000*	
72	nd	±20	0	190
			10000	171
			17490*	158
1000	170	±18	0	193
			100000	176
			115000	187
72	nd	±18	0	188
			95000	170

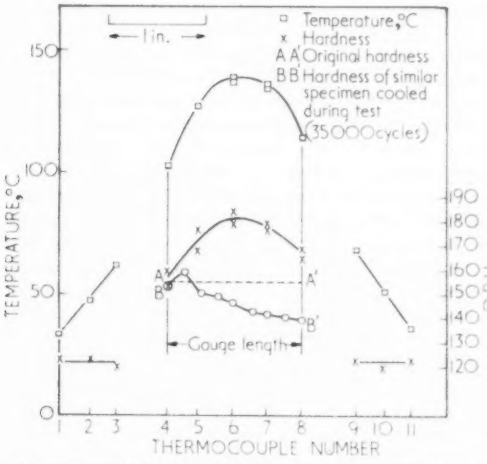
* Fractured

point, the initial 'burst' does not occur: instead, the temperature rises until fracture takes place (Fig.14). This is similar to the behaviour of strain-aged specimens at low stresses.

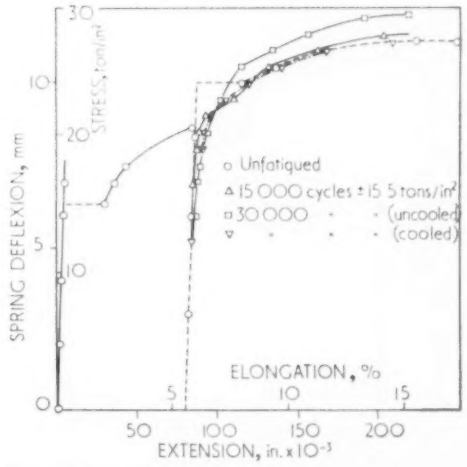
Freshly strained specimens exhibit an increase in temperature from the start of testing; an 'incubation' period is found only after strain ageing (Fig.15).

DISCUSSION

For freshly strained and for normalized specimens, the shape of the curves of temperature as a function of number of cycles is similar to those found by other workers.[8, 9] There is evidence in the literature that the curves for normalized specimens may resemble those found in this work for strain-aged specimens.[8, 9, 10] It may be that two competing processes are taking place, one tending to increase hysteresis, the other working towards fracture. If fracture occurs first, the rise to the plateau temperature cannot take place: this seems to be the case for strain-aged specimens fatigued at low stresses.



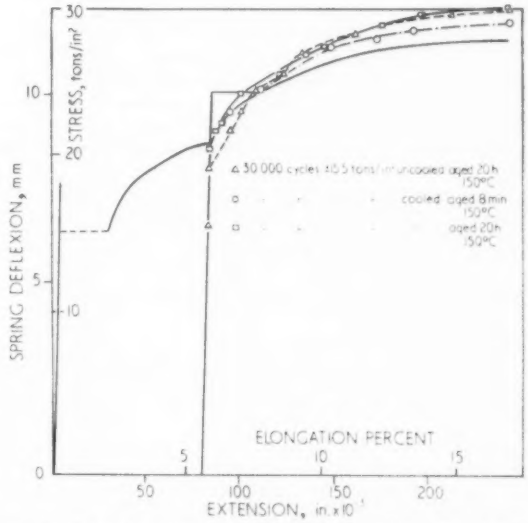
8 *Temperature distribution during test and resultant hardness. The specimen was of normalized mild steel, strained and aged to a hardness of 155 DPN, and subsequently tested at ±15·5 tons/in². The temperature distribution was measured after the plateau temperature had been obtained, i.e. after some 20000 cycles. The points outside the gauge length were measured in cylindrical portions joining the gauge length to the grips of the machine. From the temperature gradients in these portions an estimate was made of the rate of dissipation of energy in the gauge length. Hardness distribution in a similar specimen cooled during test is shown for comparison*



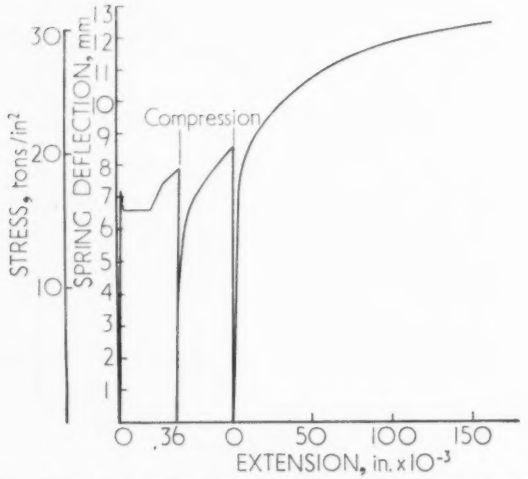
9 *Stress/strain curves after fatigue testing*

Lazan[11] has shown that there exists for steels a cyclic stress sensitivity limit, above which the energy dissipated in the specimen is a function of the number of stress reversals, and Guthrie[12] has demonstrated that this damping, a function of both stress and number of cycles, is always accompanied by the appearance of deformation markings. It is therefore clear that this energy dissipation is a result of dislocation movement and this implies that some dislocations have broken free from the Cottrell atmospheres which originally locked them. This view is supported by the evidence that the yield point is progressively removed by fatigue stressing.

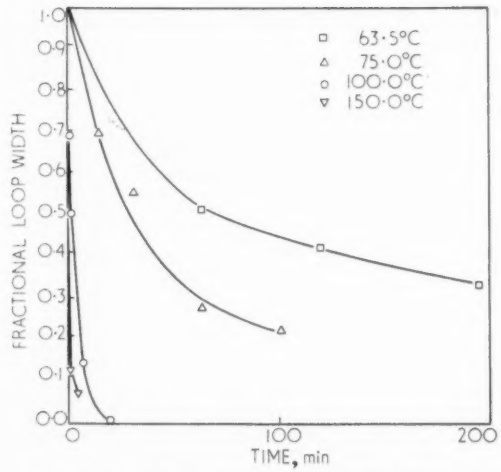
During the fatigue of strain-aged specimens, lowering of the yield point by the progressive release of more and more dislocations results in the initial reduction in hardness. As the yield point is lowered, the hysteresis losses in the specimen increase until they are sufficient to cause considerable heating. The situation is now analogous to a tensile test carried out in the


STRESS, tons/in²
SPRING DEFLEXION, mm
30 000 cycles ±15·5 tons/in² uncooled aged 20 h 150°C
" " cooled aged 8 min 150°C
" " aged 20 h 150°C
ELONGATION PERCENT
EXTENSION, in. x 10⁻³

10 *Stress/strain curves resulting from ageing after fatigue testing*



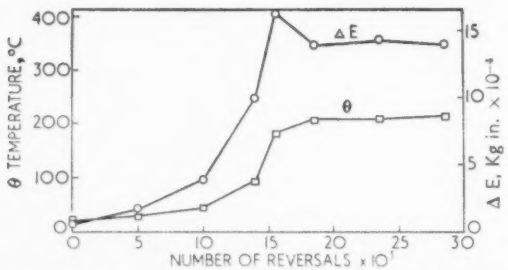
11 *Stress/strain curve after ageing following reversed plastic deformation*



13 *Changes in loop width caused by ageing at various temperatures*

blue brittle range, and a rapid increase in hardness takes place. If the specimen is cooled, the hardness continues to fall, and may even fall below the hardness of the specimen before strain ageing. In addition to softening merely by the release of dislocations from their atmospheres, some more profound alterations must therefore be taking place. A number of authors have discussed the softening of cold-worked metal by fatigue stressing.[13–18] Broom has proposed that vacancies produced by the deformation enable dislocations to climb out of their slip planes, and that this results in softening. The other workers have discussed the problem in terms of the Bauschinger effect. Both hypotheses are said to account for the observed sharpening of X-ray diffraction rings. Since work-softening may be produced by a single application of reversed deformation,[19] an analogous process may cause softening by fatigue. This would imply that in this case the role of vacancies is comparatively unimportant.

In the metal after unidirectional plastic deformation, it is thought that dislocations are piled-up against obstacles of various kinds, and that the dislocations in the pile-up repel one another. Under the action of reversed stresses, the individual dislocations may be expected to oscillate about their mean positions: because of their mutual repulsion, there will be a tendency for the length of slip plane occupied by each pile-up to increase. This would result in softening,



12 *Correlation between energy dissipated per cycle and temperature attained by the specimen, as-received, ±20 tons/in²*

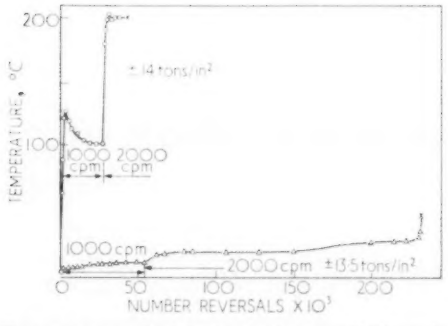
and in a reduction in local lattice curvature, and hence in a sharpening of the X-ray diffraction pattern. It is possible that such movement can occur only with the aid of point defects, and that the two points of view are complementary.

The metal after unidirectional plastic deformation is anisotropic in its behaviour under compression and tension loading. Hence dimensional changes may be expected to take place even under balanced direct stress fatigue. The mechanism outlined above should result in a shortening of a specimen originally strained in tension. A few results did indicate that this may occur, but little reliance can be placed on them, as no special precautions were taken to ensure that the stress cycle was exactly balanced.

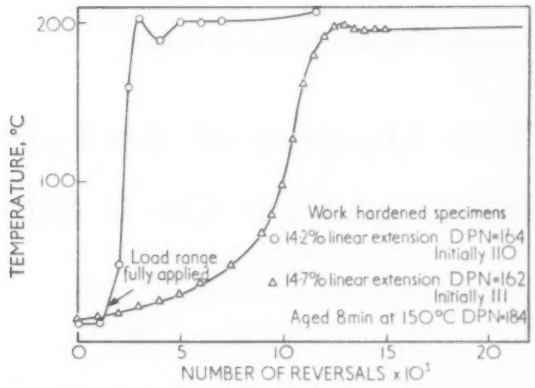
If a specimen becomes hot during test, strain ageing must take place, and hence the hardness increases. However, the hysteresis loop is not much influenced either by the temperature at which it is measured, or by the temperature the specimen is allowed to attain during test.[11, 20] For example, two estimates were made of the rate at which energy was being produced in a specimen which attained a plateau temperature of some 140°C (Fig.8): (*a*) from the size of the hysteresis loop, measured at room temperature, (*b*) from the temperature gradient in cylindrical sections between the test section and the grips of the machine, assuming heat was lost entirely by conduction into the grips of the machine. These estimates were respectively 27·5 and 34·7 W. It therefore seems probable that some dislocations are not locked at the testing temperature, and it is the movement of these which gives rise to the observed hysteresis. In hot tests, those dislocations which become locked deplete the matrix of its inter-

TABLE II As-received specimen tested at ±19 tons/in²

Total no. of cycles	Speed of testing, cycles/min	Max. temperature reached, °C	Ratio of loop widths after and before ageing 10 min at 100°C
25 000	1 000	cooled with air-blower	0·1
32 000	1 000	100	0·32
41 000	2 000	215	0·92



14 *Temperature attained during test by normalized specimen*



15 *Temperature during test at ±19 tons/in² of a strained and strain-aged specimen*

stitial solute atoms, and hence, to produce changes in yield point and loop area by locking these 'hysteresis' dislocations, diffusion over large distances must occur. This may be an explanation of the differences in ageing rate found between specimens allowed to become hot, or cooled during test. In the latter, few dislocations are locked, and all have an equal chance in competing for the interstitial solute atoms.

SUMMARY AND CONCLUSIONS

Fatigue tests have been carried out on mild steel specimens after normalizing, after straining, and after straining and ageing. Changes caused by fatigue in subsequent hardness and resistance to tensile deformation have been followed in the strain-aged specimens. Measurements of specimen temperature during fatigue have been made, as well as measurements of the energy dissipated by mechanical hysteresis. The following conclusions have been reached.

1. The fatigue testing of strain-aged specimens causes an initial decrease in hardness.

2. As this decrease in hardness occurs the energy dissipated by mechanical hysteresis increases, and, in the absence of preventive measures, the temperature of the specimen rises.

3. If the specimen temperature is allowed to increase, a 'plateau' temperature is rather suddenly attained.

4. The attainment of this plateau temperature corresponds to an increase in hardness of the specimen, to a value which may be greater than its hardness before the fatigue test.

5. If the specimen is not allowed to become hot, its hardness continues to fall until fracture takes place, even reaching a value below that of the strained specimen before ageing.

6. The changes in hardness can be correlated with changes in tensile properties. The initial decrease in hardness corresponds to the removal of the yield point of the material; and the subsequent hardening on attainment of the plateau temperature corresponds to a raising of the whole stress/strain curve above its original level.

7. The area of the hysteresis loop mapped out under reversed stressing may be reduced by ageing at slightly elevated temperatures. The activation energy for this macroscopic process (25 kcal) is perhaps consistent with the view that the migration of interstitial atoms, having an activation energy of some 20 kcal, is the microscopic process responsible.

8. For unstrained specimens, there is either a sudden rise in temperature at the beginning of test if the yield stress is exceeded, or a very slow rise to fracture if the fatigue stress lies below the yield stress. Freshly strained specimens do not exhibit an incubation period before the plateau temperature is reached.

Longer times of ageing are necessary to produce comparable changes in loop area, the hotter the specimen becomes during test.

ACKNOWLEDGMENTS

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REFERENCES

1. B. J. Lazan and T. Wu: *Proc. ASTM*, 1951, **51**, 649–678.
2. L. Bairstow: *Phil. Trans.*, 1909, (A), **210**, 35–55.
3. K. Memmler and K. Laute: *Forsch. Ing.*, 1930, **1**, 329.
4. H. Buchner: *ibid.*, 1938, **9**, 14–27.
5. P. G. Forrest and H. J. Tapsell: *Proc. IME*, 1954, **168**, 763–772.
6. C. F. Tipper: *JISI*, 1952, **172**, 143–148.
7. A. Karius, E. Gerold, and E. H. Schulz: *Arch. Eisenhüt.*, 1945, **18**, 155–159.
8. B. P. Haigh: *Trans. Farad. Soc.*, 1928, **24**, 125–137.
9. M. Hempel and E. Houdremont: *Stahl Eisen*, 1953, **73**, 1503–1511.
10. G. Welter: *Wlad Inst. Met.*, 1937, **4**, 30–39.
11. B. J. Lazan: *Trans. ASM*, 1950, **42**, 499–549.
12. M. J. Guthrie: Ph.D. thesis, Cambridge University, 1957.
13. T. Broom and R. K. Ham: *Proc. Roy. Soc.*, 1957, **242**, (A), 166–179.
14. W. A. Wood and R. L. Segall: *J. Inst. Metals*, 1957–8, **86**, 225–228.
15. H. N. Polakowski and N. Palchoudhuri: *Proc. ASTM*, 1954, **54**, 701–712.
16. L. F. Coffin and J. H. Read: 'Proceedings of the international conference on the fatigue of metals', 415: 1958, London, IME.
17. W. A. Wood [A. M. Freudenthal ed.]: 'Fatigue in aircraft structures', 1; 1956, New York, Academic Press; London, Academic Books Ltd.
18. D. S. Kemsley: *J. Inst. Metals*, 1958–9, **87**, 10–15.
19. H. N. Polakowski: *Proc. ASTM*, 1952, **52**, 1086–1097.
20. P. Ludwik and R. Scheu: *VDIZ*, 1932, **76**, 683–685.

Andrew Carnegie Research Report

The kinetics of first-stage graphitization in Fe–C and Fe–Co–C alloys

A. S. Appleton, B. Eng., Ph.D.

SYNOPSIS

The kinetics of the first-stage graphitization process in a pure Fe–C *alloy and in pure* Fe–Co–C *alloys have been studied by dilatometric and microscopic methods. The rate of graphite nucleation per unit volume and the rate of growth of graphite have been measured, and in the latter alloys, the influence of cobalt and carbon on these variables has been studied. The activation energies of the component reactions have been derived for all the alloys. The results suggest that the energy of nucleus formation is sensitive to the composition of the alloy, and that growth is controlled by the rates of cementite solution and graphite crystallization.* 1699

INTRODUCTION

IN RECENT YEARS the phenomena, and in particular the kinetics, of solid-state graphitization have been studied by methods designed to evaluate the relative importance of the component processes. Brown and Hawkes,[1] Burke and Owen,[2] and Wilcock[3] have presented views of the reaction in Fe–C–Si alloys. On the basis of dilatometric and metallographic measurements, the last three have suggested that diffusion of the constituents plays a commanding role. Activation-energy values for the nucleation and growth of the precipitated graphite, and for the solution of the carbide, have been measured and they indicated that diffusion of metal atoms away from the growing graphite is the most likely control of the growth rate. Further, Wilcock[3] has shown that this type of control is preceded by one in which the growth of the graphite spherulites is limited by the diffusion of carbon to the graphite: only at a later stage does iron diffusion away from the graphite become the controlling factor.

These conclusions were made without regard for possible 'cross-effects' between the three elements, an omission which has been criticized by Östberg.[4] Unfortunately, comprehensive data concerning the interaction of these elements during diffusion are not available, and so speculation concerning the details of graphitization based upon activation-energy measurements in this system is at present limited in its usefulness.

More recently Burke[10] has examined the growth process analytically, and has developed equations for the growth rate for each of the possible controlling mechanisms. By comparison of these relationships with experimental growth curves he concludes that the rate of cementite solution controls the greater part of the reaction in Fe–C–Si alloys. Although the correlation between the experimental and the predicted curves for a cementite solution controlled reaction is good, the analysis involves assumptions which are open to question.[11]

In the present work, an attempt has been made to circumvent these difficulties by studying graphitization in the binary Fe–C system for which diffusion data are known. The works of Bunin *et al.*[5, 6, 16] on this system have a basic limitation in their value. The presence of manganese, sulphur, and other impurities has been shown[3] to exercise a considerable effect on the characteristics and kinetics of graphitization in Fe–C–Si alloys. These workers' results, with alloys containing such elements, cannot therefore be accepted as a study of graphitization in pure Fe–C alloys.

Preliminary experiments with the ternary system Fe–Co–C showed a marked increase in the rate of graphitization of an alloy with increase in cobalt content. In other details the system behaved similarly to the Fe–C–Si system. The effect of cobalt on the diffusion rate of carbon in γ-iron, as reported by Smoluchowski,[7] appeared to offer a possible explanation for the increase in rate of graphitization, assuming carbon diffusion to be the controlling factor. A study was made to examine this possibility. As Smoluchowski's work had been disputed,[8] the dependence of carbon diffusion in austenite on the cobalt content was measured.[9]

GRAPHITIZATION OF Fe–C ALLOY

Experimental method

An alloy (F_3) containing 4·33 wt-% of carbon was prepared from BISRA oxidized high-purity iron and high-purity electrode graphite, by methods similar to those reported previously.[2, 3] Metallographic examination of several sections of the chill-cast ingot showed a completely 'white' metastable structure.

The graphitization reaction was followed at five temperatures between 1037° and 1125°C by means of a quartz dilatometer.[2, 3] Specimens for micro-examination were obtained by annealing small samples for times between zero and 100% reaction at three of these temperatures. The annealing was carried out in the dilatometer tube to ensure correspondence with the

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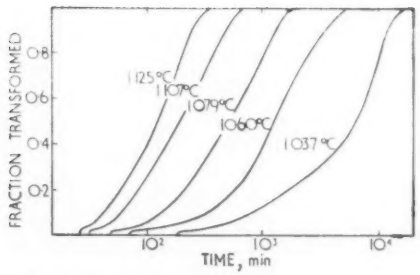


1 *Transformation curves for alloy F_3*

dilatometric results. The following measurements were made on these specimens:

(i) the volume percentage of graphite
(ii) the volume percentage of cementite
(iii) the graphite nucleation frequency per unit volume of specimen
(iv) the rate of growth of the graphite particles.

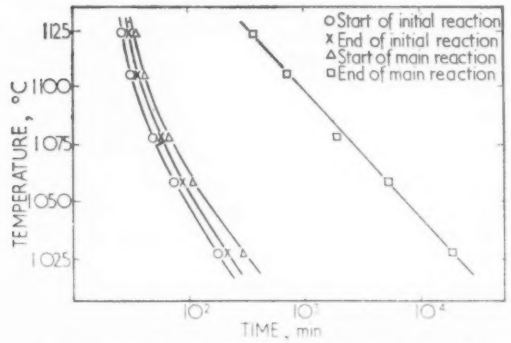
Slight surface decarburization was observed after the high-temperature vacuum-annealing treatment. The metallographic measurements were made in such a way as to avoid the decarburized layer.

The methods and calculations involved in these measurements have been discussed in earlier papers.[2, 3] The first measurement listed was used to establish the validity of the dilatometric technique as a method of following graphitization in the binary alloy. Measurements of the nucleation frequency per unit volume and the growth rate of the graphite yielded activation energies for these quantities.

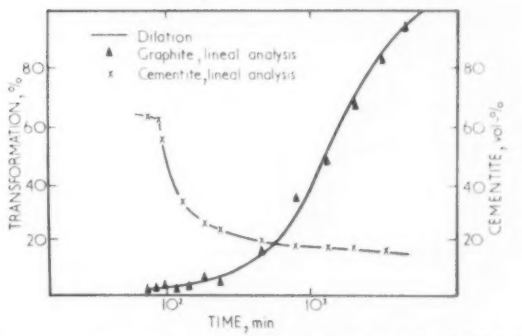
Results

The dilatometric curves in Fig.1 suggest the existence of a double-stage reaction. The time/temperature transformation diagram (Fig.2) indicates a reaction occurring at shorter times as the temperature is raised. However, neither the initial reaction nor the start of the main graphitization appear to obey the exponential time/temperature relationship which has been shown to be valid for Fe–C–Si alloy graphitization.

A large number of specimens for micro-examination were reacted in the time and temperature ranges of the initial expansion and the second incubation period. The results of the examination are exemplified in Fig.3, which shows that the volume fraction of graphite in the alloy follows the dilation curves very closely.



2 *Time/temperature transformation diagram for alloy F_3*



3 *Volume changes during graphitization of alloy F_3 at 1060°C*

both during the main reaction and in the region of the initial reaction.

The rate equation used by Burke and Owen[2] was applied to the dilatometric data. Their equation is of the form:

$$y = 1 - \exp(-t/K)^n \quad \ldots\ldots(1)$$

where y is the fraction transformed in time t, and n and K are constants.

Expressed in logarithmic form, the equation becomes

$$\text{loglog}\,(1/1-y) = n \log t - n \log K - \log 2{\cdot}3 \quad \ldots\ldots(2)$$

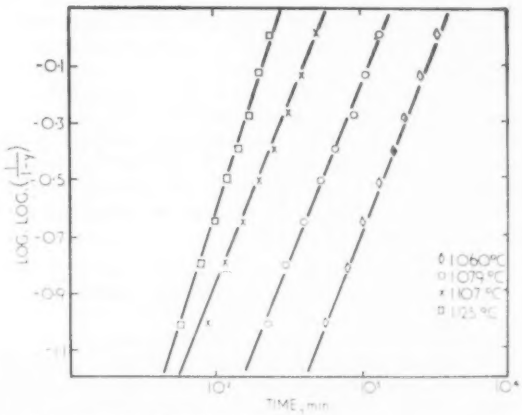
The linearity of the plot, shown in Fig.4 of loglog $(1/1-y)$ against $\log t$, demonstrates the applicability of the equation. The rate constant K has been shown to obey an Arrhenius-type relationship with temperature, namely:

$$1/K = c \exp(-Q/RT) \quad \ldots\ldots(3)$$

As $t \propto 1/K$, a plot of the logarithm of the time to a specific fraction of the reaction (say 50% reaction) against the reciprocal of the absolute temperature, yields Q, the 'energy of activation' for the transformation. The value, listed in Table I, is 148 kcal/mol.

Examination of partly reacted samples revealed the following features:

(i) graphite nucleation takes place at austenite/cementite interfaces



4 *Rate equation index plots for alloy F_3*

TABLE I Activation energies of alloys studied

Alloy		Analysis, wt-% C	Co	Fe (by difference)	Activation energies, kcal/g-mol Overall	Nucleation	Growth	
Iron–Carbon	F_3	4·33	...	95·67	148±4	118±6	235±6	228±6
Iron–Cobalt–Carbon	C_1	2·66	4·10	93·24	82±3	166±6	116±6	
	C_2	3·49	3·75	92·76	102±3	160±6	125±6	125±6
	C_3	2·14	5·95	91·91	79±3	64±6		
	C_4	3·01	5·65	91·34	67±3	76±6	90±6	121±6
	C_5	2·22	8·10	89·68	74±3	48±6	70±6	
	C_6	3·19	8·40	88·41	56±3	50±6	67±6	117±6

(ii) graphite grows in the form of large flakes. No tendency for aggregation of the latter could be observed

(iii) after only a short time of reaction, graphite flakes are usually contiguous with an austenite grain boundary. This effect is thought to arise because of the rapid austenite grain growth at the high temperatures of reaction being impeded by the presence of graphite flakes in the matrix.

It is usual to determine the rate of volume nucleation by an analysis due to Scheil.[12] In the case of a precipitate which is of flake rather than spherical form, the Scheil analysis can be used if it is assumed that the flake grows radially from the point of nucleation, at the austenite/cementite interface, in such a manner that it maintains a shape approximating to a lenticular disc.

The rate of growth G is defined as the increase in a linear dimension of the particle in unit time. The flake form of the precipitate restricted practical measurement to the longitudinal length of the flake. This dimension was measured on five different planes of polish in each partly reacted sample. As the longest flakes invariably lay along an austenite grain boundary, their actual length, not always in one dimension, was measured. The largest value obtained was then assumed to be the length of a flake which was one of the first-formed nuclei, and which had been sectioned at its maximum dimension. A plot of half this longest 'length' against the reaction time yields a curve of gradient equal to the rate of growth.

Measurements of nucleation and growth rates were made on the screen of a projection microscope. In the growth measurements, the possibility of the largest flake not being sectioned at its largest dimension was further compensated for in the graphical presentation of the measurements, where all errors from a smooth growth curve were made negative errors.

The cementite volume percentage changes during graphitization of the alloy is shown in Fig.3. A sharp decrease in the amount of cementite present in the alloy occurs during the second 'incubation period' shown by the dilatometric curve. The subsequent slow decrease in cementite volume is thought to be due to a combination of two processes.

(i) a decrease in cementite volume resulting from the normal solution of the latter during graphitization

(ii) an increasing amount of measured cementite due to precipitation of the latter from austenite on cooling from the reaction temperature.

Because of the latter effect, meaningful measurements of the cementite surface area in partly reacted samples were not possible, as no distinction could be made between carbide present in the specimen at the reaction temperature and that precipitated during the rather slow quench used in this work.

The curves of the number of flakes per unit volume against time show a linear relationship up to about 40% reaction, at which point a sharp decrease in the number occurs. This is shown for the reaction at 1107°C in Fig.5. This effect has been noted in other alloy systems,[1, 2, 13] and has been explained in terms of a dependence of the saturation concentration of carbon in austenite (with respect to graphite) on the radius of the graphite nodule. Such a relationship is not directly applicable to samples containing graphite in flake form, but the concept of a dependence of the solution potential of a precipitate particle on size does not involve the shape of the particle, and may therefore be assumed to apply in this alloy.

Following the usual practice, it is assumed that the linear nucleation rate observed from 0–40% reaction follows an Arrhenius-type relationship with temperature

$$\text{Nucleation rate } N = C \exp(-Q_n/\boldsymbol{R}T) \quad \ldots\ldots(4)$$

where C is a quantity whose variation with temperature is small compared with the rapid change of the exponential term, and where Q_n is the activation energy for nucleation.

From equation (4):

$$\log N = \log C - Q_n/2{\cdot}3\boldsymbol{R}T \quad \ldots\ldots(5)$$

The value of the activation energy for nucleation thus obtained (Table I) is 118 kcal/mol.

The curves for the longitudinal growth of flakes are shown in Fig.6*a*. They have been corrected so that zero time is the time from the 'start' of the reaction, which is taken to be the end of the first incubation period. It can be seen that the rate of growth at any given time increases with increase in temperature.

The curves suggest that growth occurs in two stages (Fig.6*b*), which, following Wilcock,[3] can be represented by

$$r^2 = K_1 t \quad \ldots\ldots(6)$$

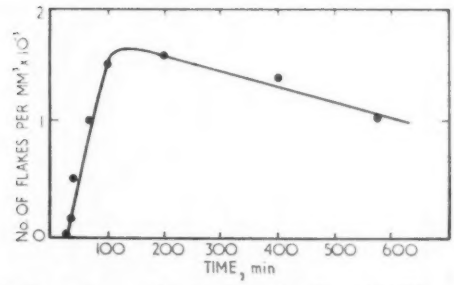
$$r^2 = K_2 t + A \quad \ldots\ldots(7)$$

where r is the 'half length' of a flake, and A is a temperature-dependent constant.

The growth constants K_1 and K_2 were assumed to obey an Arrhenius-type relationship

$$K = C \exp(-Q_G/\boldsymbol{R}T) \quad \ldots\ldots(8)$$

where C is a function varying only slowly with temperature. The activation energy Q_G was then



5 *Flake count per unit volume for alloy* F_3 *at 1 107°C*

obtained from the gradient of the line log $[(r^2-A)/t]$ vs. $1/T$ from equation (7) and log (r^2/t) vs. $1/T$ from equation (6). The derived activation energy (Table I) is about the same for both parts of the reaction and is equal to 230 kcal/mol.

Discussion of results

The first-stage graphitization of a pure iron–carbon alloy of nearly eutectic composition exhibits features that differ in many ways from those which have been found in Fe–C–Si alloys. The difference in graphite morphology, and growth along a grain boundary produce phenomena in the pure binary alloy which make comparisons with the ternary alloys of limited value.

The dilatometric and metallographic results indicate that graphitization starts and then ceases. After a second incubation period, which is temperature dependent, graphitization resumes and continues with kinetic features similar to those observed in other systems. These effects probably originate from heterogeneities introduced by the rapid cooling rate employed when the ingot was prepared. Under these conditions it appears quite possible that the alloy contains more than the equilibrium amount of cementite, owing to the preferential cooling of the austenite which, when it does separate, is depleted of carbon. Graphitization can start at the austenite/cementite interface since carbon can be drawn directly from the cementite,[13] but for it to proceed, the austenite must be in equilibrium with graphite at the temperature of reaction. It is suggested that the second incubation period represents the time required for eutectic carbide to dissolve sufficiently to raise the level of carbon in austenite to the equilibrium valve at the reaction temperature.

Turnbull and Fisher[15] have developed an expression for the rate of nucleation in a condensed system:

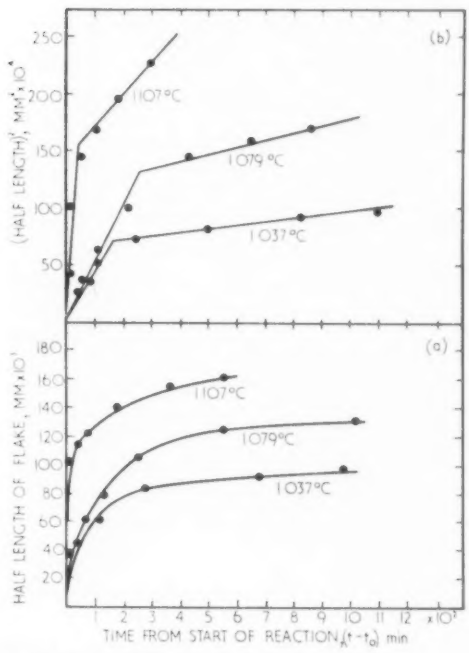
$$N=nKT/h\,[\exp(-\Delta F^*+\Delta A)/kT] \quad \ldots\ldots(9)$$

where ΔF^* is the energy required to form a nucleus, and ΔA an activation energy for the diffusion of solute atoms.

Burke and Owen[2] showed that for the Fe–C system, the use of the approximate equation

$$N=C\,[\exp(-\Delta F^*+\Delta A)/kT] \quad \ldots\ldots(10)$$

was justified. In previous studies with Fe–C–Si alloys[2,3] a value of 26 kcal/g-mol, the activation energy for carbon diffusion in austenite, has been assumed for the ΔA term. Thus for an experimental value of



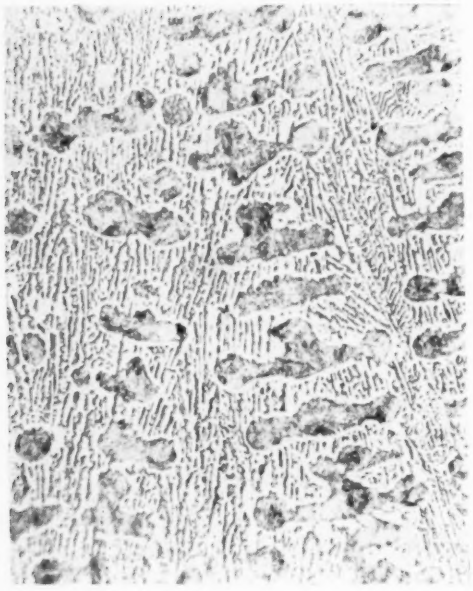
6 *Flake growth curves for alloy* F_3

$(\Delta F^*+\Delta A)=79$ kcal/g-mol, the energy to form a nucleus is about 53 kcal/g-mol. This value is much lower than that obtained in the present study where $\Delta F^*=118-26=92$ kcal/mol.

The term ΔF^* is a compound expression. It is a function of the free energy of nucleus formation, and also involves a strain-energy term, although the latter should be small at the temperature of reaction. In addition, nucleus formation at austenite/cementite interfaces will be encouraged by the decrease in energy resulting from the disappearance of the interface at the point of nucleation, This term should also be small. It would appear, therefore, that the increased value of ΔF^* in the binary alloy results from an increase in the free energy of nucleus formation which itself is a function of the volume and surface free energies of the nucleus. As no data exist for the latter, it is impossible further to allocate the observed increase in energy. However, the different shape of the macroscopic precipitate observed in this alloy suggest that possibly the surface free-energy term is important in determining the activation energy for nucleus formation.

The activation energy for both stages of growth was found to be about 230 kcal/g-mol, which is a very much larger value than that for growth of a graphite nodule in a Fe–C–Si alloy,[3] values of 30 and 60–70 kcal/g-mol being quoted for a two-stage process.

Considering the possible controlling mechanisms of the growth process in the iron–carbon alloy, both the simple diffusion processes which occur during graphitization (the diffusion of carbon atoms through the austenite towards the growing graphite and the self-diffusion of iron atoms away from the latter) have activation energies (26 and 74 kcal/g-mol respectively) much lower than that observed experimentally. Thus neither process can be in control of the reaction.



7 *As-cast* Fe–Co–C *alloy* C_2 ×860

The two other processes which might limit the growth rate are the solution of cementite and the crystallization of graphite (i.e. the transfer of carbon atoms across the austenite/graphite interface). Molinder[21] has investigated the cementite solution reaction in a high carbon steel, (1·27%C–0·20%Si–0·36%Mn–0·19%Cr–0·03%V) but only showed that the process was not limited by carbon diffusion in the austenite. However, analysis of his data for the change in cementite volume with time at different temperatures (Molinder, Fig.4) by means of the equation (1) in this paper yields activation energy values of:

$$Q_{Fe_3C_{soln.}} = 230 \pm 12 \text{ kcal/g-mol: } 750^\circ < T < 791^\circ \pm 7^\circ C$$
$$Q_{Fe_3C_{soln.}} = 65 \pm 14 \text{ kcal/g-mol: } 791^\circ \pm 7^\circ < T < 900^\circ C$$

for the process in his alloy.

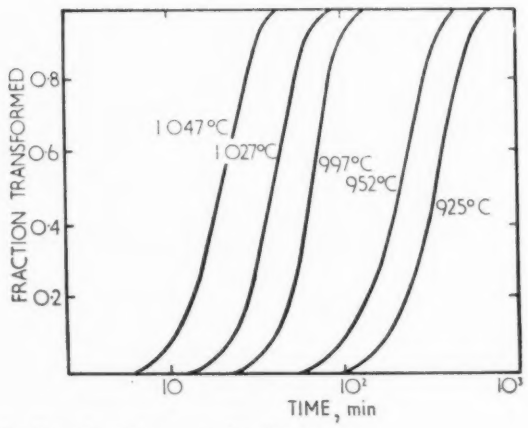
The application of this data to the present work can only be very tentative, because of the unknown effects which small quantities of Si, Mn, Cr, and V may have on the solution characteristics of the cementite.

No data are known for the activation energy for crystallization of graphite. It is impossible therefore exactly to stipulate the controlling reaction for the growth process in the Fe–C alloy under discussion. On the basis of present knowledge, it can only be concluded that the diffusion processes are fast enough to accommodate the rate of growth and that the latter is limited by either the rate of solution of cementite or the rate of crystallization of graphite.

GRAPHITIZATION IN PURE Fe–Co–C ALLOYS

A preliminary series of graphitization experiments carried out with an Fe–Co–C alloy of about 5 wt-%Co and 3 wt-%C showed that this alloy exhibited features which were comparable with the reported behaviour of Fe–C–Si alloys.[2, 13] A nearly spherulitic graphite flake aggregate* shape was produced during graphitization and the usual sigmoidal isothermal dilation curves were obtained during the reaction. These could be superimposed by translation along a logarithmic time axis.

* For convenience, the term 'nodule' will subsequently be used to describe the flake aggregate graphite precipitate found in these alloys. No special significance is implied.



8 *Transformation curves for alloy* C_5

A study was made, therefore, to investigate the influence of cobalt upon the graphitization reaction. Previous workers having suggested[3, 14] that the diffusion of carbon in austenite plays a major role in controlling graphitization rates, the reported influence[7] of cobalt on this diffusion rate offers a method of testing the validity of this suggestion. To obtain graphitization times of a convenient duration, a considerable amount of cobalt was added. To obtain carbon-diffusion data in this composition range, a large extrapolation of the available experimental data was required and so an experimental study of diffusion was undertaken, the results of which are reported elsewhere.[9]

Each alloy of a given cobalt content was duplicated to give two alloys of different carbon contents, which will be referred to as the 'high-carbon' and 'low-carbon' alloys. The analyses are given in Table I.

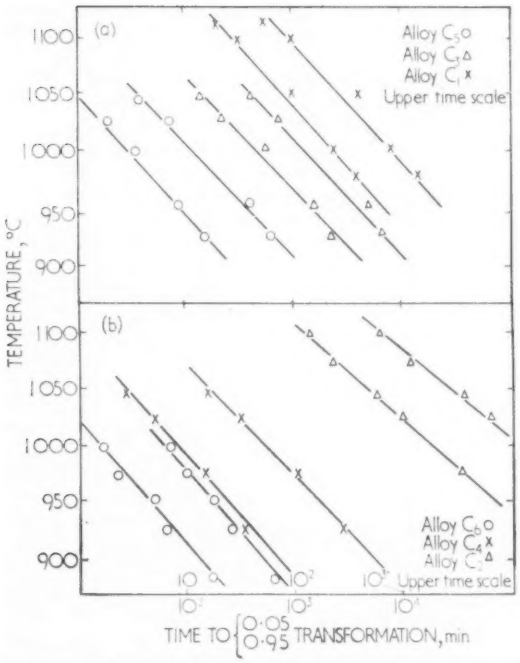
Experimental method

The alloys were made from BISRA high-purity oxidized iron, Johnson Matthey cobalt, and high-purity electrode graphite. The method of preparation was identical with that used for the iron carbide alloy. A very rapid cooling rate during casting was necessary to suppress the formation of 'undercooled'-type graphite in these alloys.

Results

A representative as-cast structure for a high-carbon alloy is shown in Fig.7. The effect of increasing cobalt in the concentrations used has, in general, a very small effect upon the relative amounts of pearlite and carbide, the volume of the former increasing very slightly, in agreement with the only published data on the ternary system.[17]

Each alloy was studied at either four or five temperatures over a range of 130°C. Typical overall transformation curves for the alloys are shown in Fig.8. It can be seen that these all have the same general form and for any alloy, of equal carbon content, can be superimposed by lateral movement along the time



9 *Time/temperature transformation curves for* (a) *alloys* C_5, C_2, *and* C_1, *and* (b) *alloys* C_6, C_4, *and* C_3

axis. This characteristic has been shown to be generally operative in Fe–C–Si alloy studies.[2, 3]

The influence of temperature on the process is shown as time/temperature transformation diagrams for the six alloys in Fig.9, the convention of showing the times to 5 and 95% transformation being used. In each case the time for graphitization is a logarithmic function of temperature, variation in the cobalt content causing a lateral movement along the time axis. The addition of carbon to alloys of similar cobalt contents shifts the 'start' of the reaction to shorter times, but has little effect upon the temperature dependence of the reaction. Carbon has been observed to have a similar effect in Fe–C–Si alloys.[18]

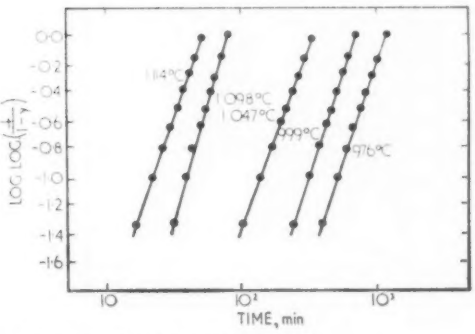
As for the iron–carbon alloy, the reaction curves were analysed by applying equation (1). From the derived logarithmic relationship (2), average values of the index $n=2{\cdot}49$ and $3{\cdot}33$ were obtained for the high- and low-carbon alloys respectively. A typical series of plots for one alloy is shown in Fig.10.

The value of the 'activation energy' for the overall reaction in each alloy was determined from equation (3). The values (Table I) indicate that an increase in cobalt content results in a decrease in activation energy, although the variation in the low-carbon alloys is small and only just larger than the experimental error.

By methods similar to those used for the Fe–C alloy, the rates of growth and nucleation during the graphitization reaction were measured at four or five temperatures.

Micro-examination of partly reacted samples revealed several features.

(i) nucleation of graphite took place at austenite/cementite interfaces



10 *Rate equation index plots for alloy* C_1

(ii) the graphite produced during graphitization was of a flake aggregate type. The degree of compactness of the aggregate was found to increase with increasing cobalt and with decrease in reaction temperature.

The latter phenomenon has been reported[19] in Fe–C–Si alloys.

The volume percentage variation of graphite during the reaction was measured at one temperature for each alloy. This was done, as in the Fe–C alloy graphitization analysis, to confirm that the dilatometric method was a valid means of following the graphitization reaction in these alloys. This was found to be so in all cases.

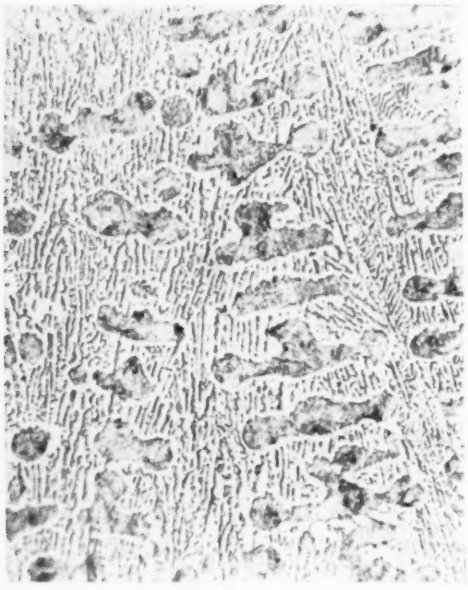
The rate of nucleation N was determined using the Scheil analysis. A graph of the number of nodules per unit volume against time yields a curve for which the initial constant gradient equals the rate of nucleation. All the curves show a maximum number of nodules at about 40% reaction.

In general, the number of nodules per unit volume at corresponding positions on the overall reaction curve for any one alloy do not vary with temperature, and, within limits, are the same for all alloys of similar carbon content.

The activation energies, derived from the variation of the rates of nucleation with temperature (equation 5) are tabulated in Table I.

The rate of growth G, defined as the increase of a linear dimension in unit time, was determined by techniques discussed elsewhere.[2, 3] Figure 11*a* shows a typical series of growth curves for one alloy, where the end of the incubation period at each temperature has again been taken as zero time. The data presented in Fig.12 show that the initial rate of growth increases with increase in temperature. The influence of cobalt on this growth rate in the high-carbon alloys is shown in Fig.13. It can be seen that the rate increases rapidly with increasing cobalt, the increase becoming more pronounced as the cobalt content of the alloy rises.

The growth curves were found to obey a parabolic relationship with time of the general form $r^2=K_G t+A$ where A is a temperature-dependent constant, and K_G is the rate constant for growth. Figure 11*b* shows the linear relationships obtained when the square of the radius is plotted against time. The constant A is found to be equal to zero throughout the reaction for the alloys of lower carbon content, and for the initial period of the reaction in high-carbon alloys: for the



7 *As-cast* Fe–Co–C *alloy* C_2 ×860

The two other processes which might limit the growth rate are the solution of cementite and the crystallization of graphite (i.e. the transfer of carbon atoms across the austenite/graphite interface). Molinder[21] has investigated the cementite solution reaction in a high carbon steel, (1·27%C–0·20%Si–0·36%Mn–0·19%Cr–0·03%V) but only showed that the process was not limited by carbon diffusion in the austenite. However, analysis of his data for the change in cementite volume with time at different temperatures (Molinder, Fig.4) by means of the equation (1) in this paper yields activation energy values of:

$Q\mathrm{Fe_3C_{soln.}} = 230 \pm 12$ kcal/g-mol: $750° < T < 791° \pm 7°C$
$Q\mathrm{Fe_3C_{soln.}} = 65 \pm 14$ kcal/g-mol: $791° \pm 7° < T < 900°C$

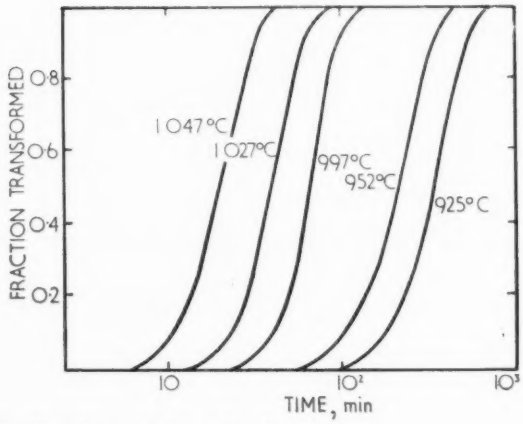
for the process in his alloy.

The application of this data to the present work can only be very tentative, because of the unknown effects which small quantities of Si, Mn, Cr, and V may have on the solution characteristics of the cementite.

No data are known for the activation energy for crystallization of graphite. It is impossible therefore exactly to stipulate the controlling reaction for the growth process in the Fe–C alloy under discussion. On the basis of present knowledge, it can only be concluded that the diffusion processes are fast enough to accommodate the rate of growth and that the latter is limited by either the rate of solution of cementite or the rate of crystallization of graphite.

GRAPHITIZATION IN PURE Fe–Co–C ALLOYS

A preliminary series of graphitization experiments carried out with an Fe–Co–C alloy of about 5 wt-%Co and 3 wt-%C showed that this alloy exhibited features which were comparable with the reported behaviour of Fe–C–Si alloys.[2, 13] A nearly spherulitic graphite flake aggregate* shape was produced during graphitization and the usual sigmoidal isothermal dilation curves were obtained during the reaction. These could be superimposed by translation along a logarithmic time axis.



8 *Transformation curves for alloy* C_5

A study was made, therefore, to investigate the influence of cobalt upon the graphitization reaction. Previous workers having suggested[3, 14] that the diffusion of carbon in austenite plays a major role in controlling graphitization rates, the reported influence[7] of cobalt on this diffusion rate offers a method of testing the validity of this suggestion. To obtain graphitization times of a convenient duration, a considerable amount of cobalt was added. To obtain carbon-diffusion data in this composition range, a large extrapolation of the available experimental data was required and so an experimental study of diffusion was undertaken, the results of which are reported elsewhere.[9]

Each alloy of a given cobalt content was duplicated to give two alloys of different carbon contents, which will be referred to as the 'high-carbon' and 'low-carbon' alloys. The analyses are given in Table I.

Experimental method

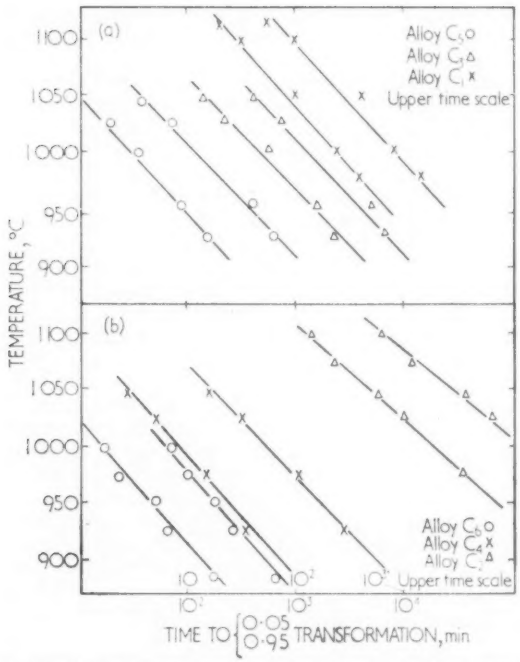
The alloys were made from BISRA high-purity oxidized iron, Johnson Matthey cobalt, and high-purity electrode graphite. The method of preparation was identical with that used for the iron carbide alloy. A very rapid cooling rate during casting was necessary to suppress the formation of 'undercooled'-type graphite in these alloys.

Results

A representative as-cast structure for a high-carbon alloy is shown in Fig.7. The effect of increasing cobalt in the concentrations used has, in general, a very small effect upon the relative amounts of pearlite and carbide, the volume of the former increasing very slightly, in agreement with the only published data on the ternary system.[17]

Each alloy was studied at either four or five temperatures over a range of 130°C. Typical overall transformation curves for the alloys are shown in Fig.8. It can be seen that these all have the same general form and for any alloy, of equal carbon content, can be superimposed by lateral movement along the time

* For convenience, the term 'nodule' will subsequently be used to describe the flake aggregate graphite precipitate found in these alloys. No special significance is implied.



9 *Time/temperature transformation curves for* (a) *alloys* C_5, C_3, *and* C_1, *and* (b) *alloys* C_6, C_4, *and* C_2

axis. This characteristic has been shown to be generally operative in Fe–C–Si alloy studies.[2, 3]

The influence of temperature on the process is shown as time/temperature transformation diagrams for the six alloys in Fig.9, the convention of showing the times to 5 and 95% transformation being used. In each case the time for graphitization is a logarithmic function of temperature, variation in the cobalt content causing a lateral movement along the time axis. The addition of carbon to alloys of similar cobalt contents shifts the 'start' of the reaction to shorter times, but has little effect upon the temperature dependence of the reaction. Carbon has been observed to have a similar effect in Fe–C–Si alloys.[18]

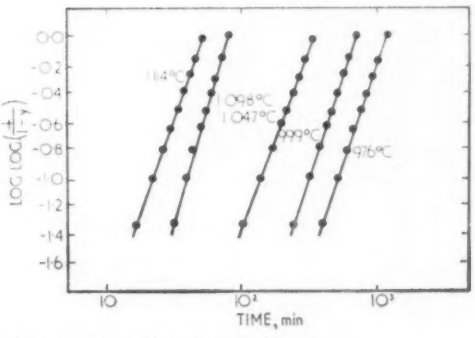
As for the iron–carbon alloy, the reaction curves were analysed by applying equation (1). From the derived logarithmic relationship (2), average values of the index $n=2{\cdot}49$ and 3·33 were obtained for the high- and low-carbon alloys respectively. A typical series of plots for one alloy is shown in Fig.10.

The value of the 'activation energy' for the overall reaction in each alloy was determined from equation (3). The values (Table I) indicate that an increase in cobalt content results in a decrease in activation energy, although the variation in the low-carbon alloys is small and only just larger than the experimental error.

By methods similar to those used for the Fe–C alloy, the rates of growth and nucleation during the graphitization reaction were measured at four or five temperatures.

Micro-examination of partly reacted samples revealed several features.

(i) nucleation of graphite took place at austenite/cementite interfaces



10 *Rate equation index plots for alloy* C_1

(ii) the graphite produced during graphitization was of a flake aggregate type. The degree of compactness of the aggregate was found to increase with increasing cobalt and with decrease in reaction temperature.

The latter phenomenon has been reported[19] in Fe–C–Si alloys.

The volume percentage variation of graphite during the reaction was measured at one temperature for each alloy. This was done, as in the Fe–C alloy graphitization analysis, to confirm that the dilatometric method was a valid means of following the graphitization reaction in these alloys. This was found to be so in all cases.

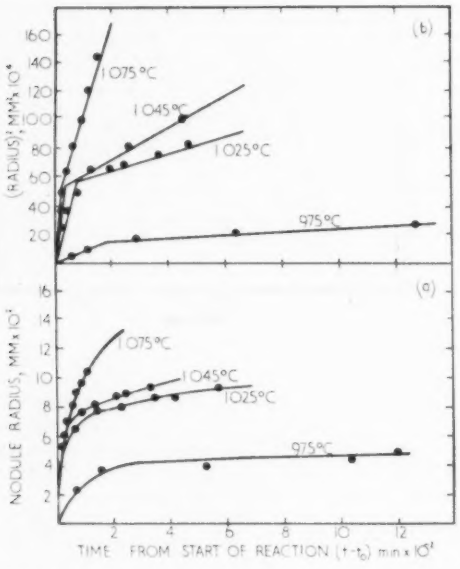
The rate of nucleation N was determined using the Scheil analysis. A graph of the number of nodules per unit volume against time yields a curve for which the initial constant gradient equals the rate of nucleation. All the curves show a maximum number of nodules at about 40% reaction.

In general, the number of nodules per unit volume at corresponding positions on the overall reaction curve for any one alloy do not vary with temperature, and, within limits, are the same for all alloys of similar carbon content.

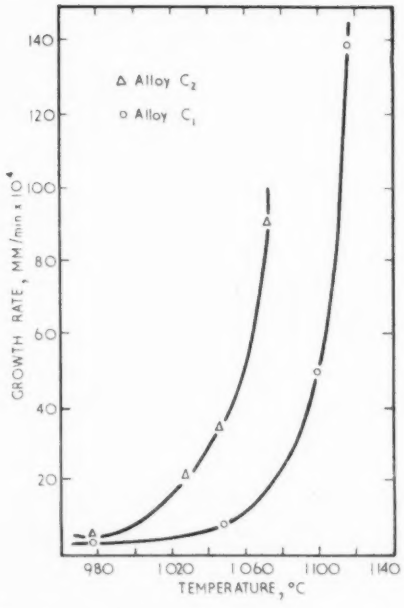
The activation energies, derived from the variation of the rates of nucleation with temperature (equation 5) are tabulated in Table I.

The rate of growth G, defined as the increase of a linear dimension in unit time, was determined by techniques discussed elsewhere.[2, 3] Figure 11*a* shows a typical series of growth curves for one alloy, where the end of the incubation period at each temperature has again been taken as zero time. The data presented in Fig.12 show that the initial rate of growth increases with increase in temperature. The influence of cobalt on this growth rate in the high-carbon alloys is shown in Fig.13. It can be seen that the rate increases rapidly with increasing cobalt, the increase becoming more pronounced as the cobalt content of the alloy rises.

The growth curves were found to obey a parabolic relationship with time of the general form $r^2=K_G t+A$ where A is a temperature-dependent constant, and K_G is the rate constant for growth. Figure 11*b* shows the linear relationships obtained when the square of the radius is plotted against time. The constant A is found to be equal to zero throughout the reaction for the alloys of lower carbon content, and for the initial period of the reaction in high-carbon alloys: for the



11 *Growth curves for alloy C_2*



12 *Effect of temperature on initial growth rate*

latter part of the reaction in high carbon alloys it assumes a positive value.

From the temperature dependence of the rate constant equation (8) the activation energies for growth were derived as before. The values are tabulated in Table I.

Discussion

The process of graphitization in Fe–Co–C alloys is seen to be superficially similar to that which has been shown to take place in Fe–C–Si alloys. The morphology of the graphite is similar, the nucleation of the graphite takes place at corresponding surfaces, and the growth characteristics, at least for the higher-carbon alloys, would appear common to both systems. However, in the assessment of the results, several distinguishing characteristics of the Fe–Co–C system must be considered.

It has been shown[7, 9] that, unlike other alloy additions, cobalt markedly increases the rate of carbon diffusion in austenite. It seems probable, therefore, that cobalt will influence the thermodynamic parameters of the system, such as surface energies, free energies of formation, activity, etc.

The composition of the austenite in the vicinity of the cementite/austenite interfaces involved in the nucleation of the graphite, as well as that surrounding the growing graphite aggregates, must be considered. The carbide present in the alloys under consideration was found to be cementite, with perhaps a small amount of cobalt substituted in the lattice. During the rapid solidification rates on casting which were employed in these alloys, cobalt which was rejected by the growing cementite at the eutectic would not have time to diffuse into the existing austenite grains, and a 'coring' effect would be produced. Considerations of nucleation at the austenite/cementite interfaces must take into account this enhanced cobalt concentration. In addition, only a gradual diminution of this concentration will occur in the relatively short times involved in graphitization.

Equation (10) may be applied to the nucleation data. The variation of the ΔA term, the activation energy for diffusion of the solute atoms, is small compared to the large variation of the total $(\Delta F^* + \Delta A)$, even allowing for high cobalt concentrations at the austenite/cementite interface.

The probable values are therefore:

$$(\Delta F^* + \Delta A) \text{ experimental} = 50\text{–}160 \text{ kcal/mol}$$
$$\Delta A \text{ experimental}^9 = \text{approx. } 25 \text{ kcal/mol}$$
$$\Delta F^* = 25\text{–}135 \text{ kcal/mol}$$

It is seen that the energy of nucleus formation is very sensitive to the cobalt present in the alloy, but is apparently independent of the carbon concentration in the range studied (Table I). This latter would be expected, as the carbon concentration does not alter the physical situation at a nucleation site on an austenite/cementite interface. Speculation regarding the possible mechanisms by which ΔF^* is decreased as the cobalt concentration rises are not possible because of the complete lack of data regarding the component terms (i.e. volume free energy, surface energy, etc.) of this expression.

The radius of a graphite nodule has been shown to increase roughly parabolically with time during the graphitization reaction in all the alloys studied. The activation energy values for growth (Table I) indicate:

(i) a two-stage process is operative in high-carbon alloys
(ii) the whole reaction in low-carbon alloys and the initial process in high-carbon alloys are sensitive to the cobalt content of the alloy but are independent of the carbon concentration
(iii) the later stage of the process in high-carbon alloys is independent of cobalt concentration.

Comparing the activation energy values with those for the possible controlling processes:

(i) diffusion of carbon in the austenite to the growing graphite interface can be associated with an energy of not more than 30 kcal/mol
(ii) the diffusion rate of iron away from the growing graphite interface would not, it is thought, be much affected by the presence of cobalt. Hence the value for the self-diffusion of iron = 74 kcal/g-mol[20] would be applicable.
(iii) the diffusion of cobalt in γ-iron away from the growing graphite interface has been shown[8] to have an activation energy similar to the values for nickel and manganese diffusion = 67 kcal/g-mol.

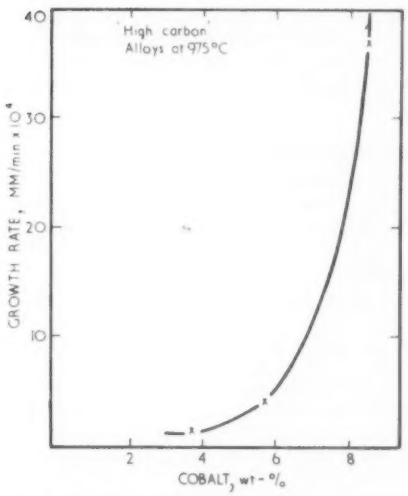
It is apparent that none of these processes can be controlling the growth reaction at any stage in the alloys under discussion. Activation-energy values for the two remaining possible control processes, namely, the rate of solution of cementite and the rate of crystallization of graphite, are unknown for these alloys.

Considering (iii) above, it is apparent that as the later stage of the reaction in high-carbon alloys is controlled by a process independent of the cobalt content of the alloy, this process must be occurring at an interface (either graphite/austenite or austenite/cementite) where the cobalt concentration is constant or equal to zero. This is obviously not the situation at the graphite/austenite interface. Here, the growing graphite rejects cobalt (and iron) and maintains a gradient for the diffusion of the latter away from the interface. The maximum value will always be some function of the original cobalt concentration. Hence it is concluded that the rate of crystallization of graphite is not responsible for the constant activation energy found for the final stage of graphite growth in the high-carbon alloy.

Alternatively, it is possible to account for this phenomenon in terms of the rate of solution to cementite. As the latter decomposes, the carbon diffuses to a graphite particle while the iron from the orthorhombic cementite forms fcc austenite. As the cobalt concentration in the cementite is very small the region around a partly dissolved carbide particle will be depleted in cobalt with respect to the rest of the austenite. Cobalt will diffuse into this region relatively slowly.

The cementite in a high-carbon alloy will, in general, be of a larger particle size than that in the low-carbon alloys. Thus, as the carbide dissolves, the austenite/cementite interface will move further away from its original position in the high-carbon alloy than in the low-carbon alloy, and hence into regions of lower and lower cobalt.

An assumption must now be made which, although as yet untested by experiment, appears to be reasonable. The activation energy for the solution of cementite is assumed to be decreased by the presence of cobalt at the austenite/cementite interface. Hence it follows that as the austenite/cementite interface retreats and the cobalt content of the austenite in contact with the latter decreases, the activation energy for cementite solution will increase until, in the high-carbon alloys, it assumes control of the overall growth reaction. Thus, it is concluded that the second stage of the growth process in the high-carbon alloys is controlled by the rate of solution of the cementite.



13 *Effect of cobalt on initial growth rate*

By comparison of activation energy values it follows, therefore, that the first stage of growth in the high-carbon alloys, and the complete growth process in the low-carbon alloys, is controlled by the rate of crystallization of graphite.

Burke[10] has deduced from analytical considerations that the solution of cementite controls the majority of the growth process in Fe–C–Si alloys. The analysis predicts a linear growth rate with a deviation at very short times which is associated with a process controlled by the rate of graphite crystallization. A relationship for the index 'n' in equation (1) $n=3a+b$ where a is the index of the growth equation $r=K_G t^a$ and where b is the index of the nucleation equation $N=K_N t^b$ has been used by Burke to support the prediction of a linear growth rate, as in Fe–C–Si alloys $n=4$, $b=1$, and hence $a=1$.

In the present study, values of $n=2{\cdot}5\pm0{\cdot}3$ and $3{\cdot}3\pm0{\cdot}8$ were obtained for the high- and low-carbon alloys respectively. For these alloys $b=1$. This yields $a=0{\cdot}5\pm0{\cdot}1$ for the high-carbon alloys, and $a=0{\cdot}75\pm0{\cdot}25$ for the low-carbon alloys.

It is apparent therefore that the analysis of the growth curves in terms of a parabolic rate law ($a=1/2$) was a reasonable approximation in these alloys. The reasons for the higher values of a in the low-carbon alloys is not apparent at the present time.

CONCLUSIONS

(1) The first-stage graphitization of a pure iron–carbon alloy results in the formation of flake graphite, the growth of which is limited by either the rate of solution of cementite or the rate of crystallization of carbon atoms on the graphite.

(2) The first-stage graphitization of pure iron–cobalt–carbon alloys in the range of compositions studied results in the formation of flake aggregate type graphite spherulites. The activation energy for nucleation of these is sensitive to the cobalt content of the alloy. The growth of the graphite is limited by the rate of crystallization of carbon throughout the whole

reaction in the alloys of lower carbon. In high-carbon alloys, this control mechanism is applicable for the initial part of the growth process only. At a later stage, the rate of solution of cementite controls the growth of the graphite.

ACKNOWLEDGMENTS

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REFERENCES

1. B. F. Brown and M. F. Hawkes: *Trans. AFS*, 1951, **59,** 181–200.
2. J. Burke and W. S. Owen: *JISI*, 1954, **176,** 147–155.
3. J. Wilcock: Ph.D. thesis, Liverpool University, 1956.
4. G. Östberg: *JISI*, 1957, **186,** 49–50.
5. K. P. Bunin and I. V. Salli: *Doklady AN*, 1952, **83,** (6), 841–842.
6. K. P. Bunin and T. M. Shpak: *Lit. Proizv.*, 1954, **3,** 26.
7. R. Smoluchowski: *Phys. Rev.*, 1942, **62,** 539.
8. M. F. Hawkes and R. F. Mehl: *Metals Technology*, 1947, Tech. Publ. 2211.
9. A. S. Appleton: 'The diffusion of carbon in Fe–Co–C alloys', (to be published).
10. J. Burke: *Acta Met.*, 1959, **7,** 268.
11. A. S. Appleton: in discussion of ref.10.
12. E. Scheil: *Zeitschrift für anorganische und allgemeine Chemie*, 1931, **201,** 259–264.
13. W. S. Owen and J. Wilcock: *JISI*, 1956, **182,** 38–43.
14. W. S. Owen: Conference on cast irons, Birmingham, 1955.
15. D. Turnbull and J. C. Fisher: *J. Chem. Phys.*, 1949, **17,** 71.
16. K. P. Bunin and N. M. Danil'chenko: *Doklady AN*, 1950, **72,** (5), 889–890.
17. C. J. Smithells: 'Metals Reference Book', 360; 1949, London, Butterworths.
18. J. E. Rehder: *Trans. AFS*, 1949, **57,** 173.
19. A. Hultgren and G. Östberg: *JISI*, 1954, **176,** 351–365.
20. C. E. Birchenall and R. F. Mehl: *J. Met.*, 1950, **2,** 144–149.
21. G. Molinder: *Acta Met.*, 1956, **4,** 565.

Letter to the Editor

Ergonomic investigations into the design of master controllers

IN THE PAPER of this title* an experiment was described concerning the so-called 'feel' of hand controllers. The report of this experiment was at that time incomplete though it had been given a provisional reference number quoted in the references to the article as: A. Box and R. G. Sell: BISRA unpublished report no. PE/NE/83/58.

The report is now complete and has been approved for restricted circulation under the title and reference no. OR/HF/47/59: 'The effect of three aspects of controller design on operating performance' by A. Box and R. G. Sell.

More important than the change in reference number, however, is the fact that more detailed analysis of the results of the experiment has revealed conclusions somewhat different from the conclusions given in the original article.

The experiment was concerned with investigating the effect on performance of three aspects of hand controller design, two of which were to do with detailed aspects of the design of the location mechanism for the speed steps and the third of which concerned the provision or not of a safety-stop latch for the OFF position. Full details of these variables and the experimental procedure were given in the original article.

The conclusions reached now read:

(1) The results of the experiment established beyond reasonable doubt that some form of location mechanism (i.e. as distinct from providing no location at all) materially improves performance.

(2) From the viewpoint of operating performance only, it appears sufficient to provide the operator with a clear indication that the controller is in the OFF position, i.e. it is necessary only to provide location for this position.

(3) In the experiment, the OFF position location consisting of a single notch and described as giving location only when the handle was in the OFF position was consistently superior to the second design of OFF position studied which gave indication both when the handle was in the OFF position and when it was moving from the adjacent notches.

(4) If, however, it is considered necessary for reasons other than operating performance to provide the controller with location for each speed step then the location mechanism described as giving a light smooth feel is to be preferred to that giving a more positive and tighter feel though this result was less clear-cut. In this case extra location for the OFF position should be provided.

(5) The effect of the stop-latch on operating performance was marginal only, but the provision of such a latch is nevertheless recommended on safety grounds.

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* A. Box and R. G. Sell: *JISI*, 1958, **190,** 178–187

The constitution of the iron–niobium–silicon system

H. J. Goldschmidt, D.Sc., F.Inst.P.

SYNOPSIS

The ternary system iron–niobium–silicon has been investigated by X-ray analysis for 1000°C equilibrium. There occur 15 binary and at least six, possibly nine, ternary phases; the diagram arising is complex, particularly in the regions richer in iron and niobium.

Detailed results are presented and discussed; one outcome is that the iron–niobium Laves phase, besides possessing considerable Fe⇄Nb *variability, has a wide solubility for silicon, with characteristic changes in lattice dimensions. Silicon also dissolves appreciably in a new* Fe–Nb *sigma phase.*

Other properties recorded on the alloys are approximate melting points, ferromagnetism, and high-temperature oxidation resistance. Areas with promising oxidation resistance are indicated, and a first attempt is made to relate this to the structure of oxide films formed.

Some of the phases found are liable to play a significant part in the development of precipitation-hardening high-temperature alloys. 1659

THE TRANSITION METALS of groups IV, V, and VI of the periodic table are becoming increasingly prominent as potentially useful bases for gas-turbine alloys. In particular, niobium has received much recent attention because of its good ductility and high-temperature properties; however, this metal suffers from very poor oxidation resistance above about 500°C, so that one object must be the search for alloy additions to enhance this property. Such added elements can be divided into the following classes, (*a*) those, like silicon and aluminium, which, in other alloy systems, are known inherently to contribute to protective oxide formation; (*b*) the group IV, V, VI transition metals other than niobium, but solution-forming and of comparable atomic sizes, such as titanium, molybdenum, or tungsten; and (*c*) the iron group metals which tend to form intermetallic compounds with niobium and therefore are potential precipitation-hardening agents.

The ternary system iron–niobium–silicon typifies a combination of the first and third classes. The system is also of interest, because niobium additions to iron are known to cause age-hardening effects. Furthermore, in certain established creep-resisting steels[1, 2] a ternary iron–niobium-silicide has been found to occur by the writer[3]; the existence of this silicide was confirmed in recent Russian work,[4] whilst the investigations of Beattie[5] again reveal silicides in heat-resisting alloys and bring out their importance.

A point of fundamental interest is that the atomic sizes of the three component metals are such that silicon is dissolved substitutionally in iron, interstitially in niobium (as will be shown below); this borderline position of silicon *vis-à-vis* iron and niobium suggests a high degree of complexity in the ternary field and a liability to form metastable and heat-treatment sensitive equilibria.

No previous work on the ternary system Fe–Nb–Si is known. The three surrounding binary systems have, however, been investigated, as will be discussed in the relevant sections below.

EXPERIMENTAL METHOD

The Fe–Nb–Si system was studied by X-ray diffraction analysis, using powder-photography of alloys in equilibrium at 1000°C. In the early stages the method of alloy preparation was that of sintered compacts, but this approach frequently failed to establish satisfactory equilibria, and entailed a considerable risk of contamination from contacting materials to which niobium is particularly prone. For the principal investigation, therefore, the method of melting small ingots was adopted. Nevertheless, the sintered samples proved of value in tracing the kinetics leading to the equilibria attained in the melted alloys.

The raw materials used were Johnson Matthey spectroscopically pure iron, niobium, and silicon of analysis shown in Table I.

TABLE I Typical analysis of raw materials used

Element, wt-%	Iron	Niobium	Silicon
Fe	>99·6	0·01	0·001
Nb	...	>99·65	...
Si	0·0007	0·02	...
Mn	0·0003	...	...
Cr	...	0·0005	...
Ni	0·0002	0·0003	...
Cu	0·0001	0·0001	0·0001
Mg	0·0001	0·0002	<0·0001
Na	0·0001	<0·0001	...
Ag	<0·0001	...	<0·0001
Ge	...	...	0·001
Al	...	...	<0·0001
Ca	...	0·0002	<0·0001
Ta	...	0·3	...
Sn	...	0·005	...
Ti	...	0·002	...
C	0·03	<0·005	...

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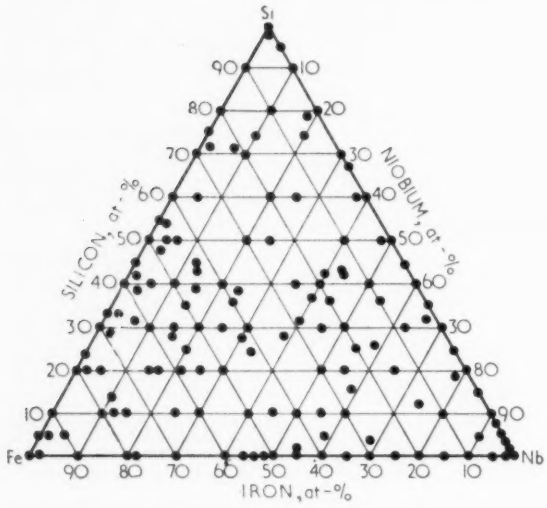
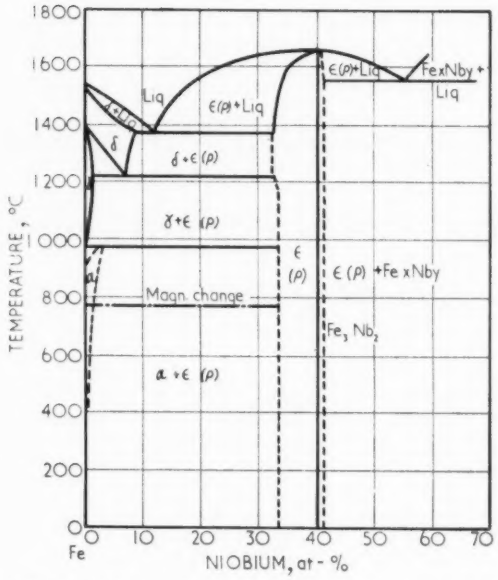
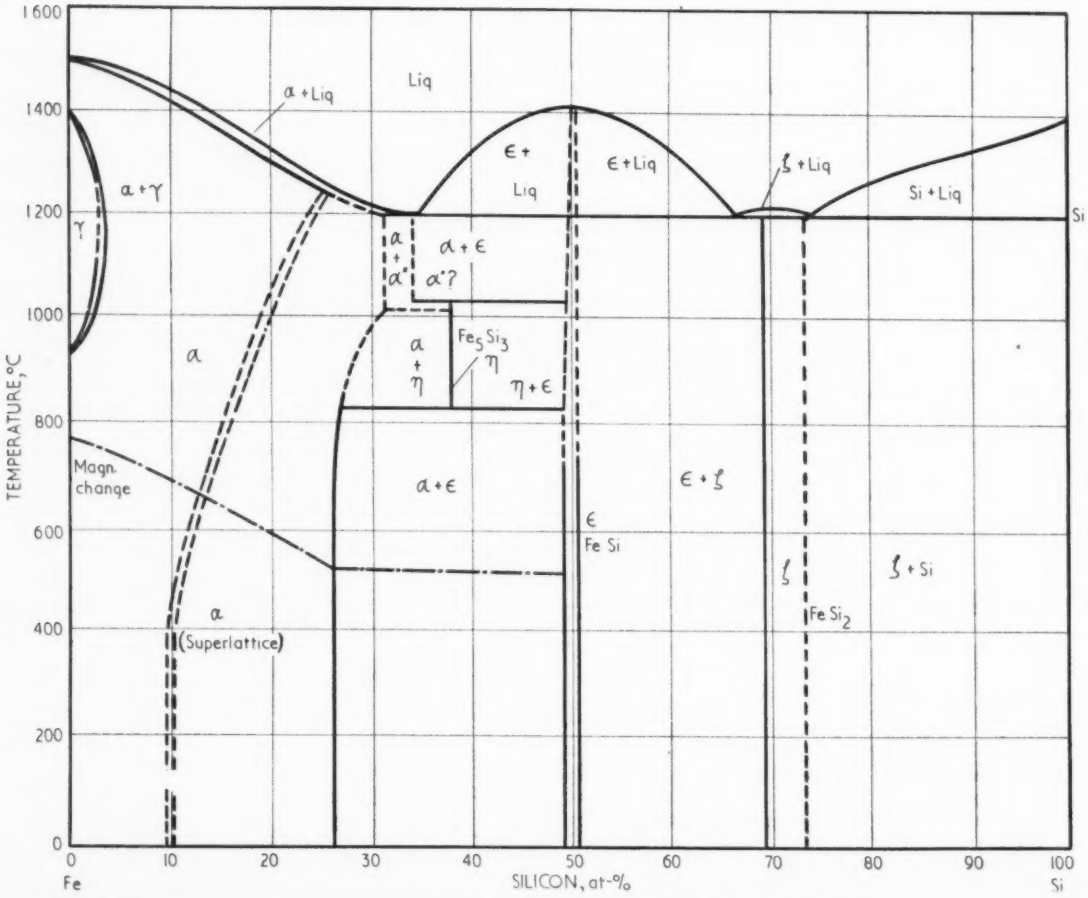


1 *Composition of alloys*



3 *The iron–niobium diagram according to Eggers and Peter*



2 *The iron–silicon diagram, consensus of data according to Hansen (α″ is a doubtful further bcc phase)*

The ingots weighed roughly 5 g, and were melted in an argon-filled laboratory arc furnace using a tungsten electrode and water-cooled copper hearth. A zirconium or titanium button was melted immediately preceding each alloy, in order to serve as a getter. Melting lasted about 3 min, but for homogenization the sample was kept just below its observed freezing point (or solidus where applying) for a prolonged period. The loss in weight was generally insignificant, but in some cases minor corrections in composition had to be made owing to preferential vaporization of one component.

Powders were prepared by crushing or filing, depending on the brittleness or ductility of the alloy, and annealed in evacuated silica capsules at 1000°C for 14 days, then water quenched. Although the 1000°C section was studied in the main, occasional heat-treatments were given at higher and at lower temperatures, in order to gain subsidiary data on phase-changes; the time-periods varied and will be mentioned for the different cases.

For niobium-rich alloys difficulty was experienced through contamination during the anneal. Auxiliary experiments, however, showed that effective protection could be obtained by embedding the alloy in niobium powder inside the silica capsule, or by using the core of small lumps. The latter method was generally adopted for niobium-rich alloys. The total number of alloys prepared and examined was about 250. Figure 1 shows the principal compositions, upon which the final results were based.

The X-ray technique was that of normal Debye-Scherrer photography, using cobalt K_α radiation.

Although the determination of phase equilibria formed the principal object, approximate melting points, ferro-magnetism, and oxidation-resistance were also examined and the results included.

Compositions will be expressed in *atomic* percent throughout, unless otherwise stated.

RESULTS (CONSTITUTIONAL)

The binary sides

The iron–silicon system

The iron–silicon system is well established from previous work[6, 9] shown in Fig.2.[10] The agreement, as far as the present work is concerned, is satisfactory and no new results are claimed. The principal features observed were as follows: silicon forms an extensive series of solid solutions in α-iron which are known to be substitutional. The lattice is contracted by silicon from $a_0 = 2{\cdot}8604$ kX for pure iron to 2·8080 kX at 32%Si, the solution boundary at 1000°C. The α-lattice-parameters found here agree with those given by Farquhar *et al.*[6] Alloys low in silicon show a characteristic martensite-like structure, when quenched from 1000°C, owing to the γ-loop. The Fe_3Si superlattice occurs from about 20%Si to the solution boundary, consistent with Fig.2.

The η phase, Fe_5Si_3, was stable over a restricted high-temperature region only (*see* Fig.2); this included 1000°C, so that the compound is in the present diagram. The stable compounds FeSi (ϵ) and $FeSi_2$ (ζ) were also observed prominently. The $FeSi_2$ phase was found to possess a finite homogeneity range towards silicon, shown by a decrease in lattice-dimensions. The phase has sometimes been given the formula $FeSi_3$, and the above variability would indicate a tendency towards this composition. $FeSi_2$ and silicon are in direct equilibrium. Iron is insoluble in primary silicon.

The iron–niobium system

The principal previous work on the iron–niobium system was that of Eggers and Peter[11] (Fig.3) and of Peter,[12] whilst Genders and Harrison[13] have determined the solubility of niobium in α and γ iron. Compounds previously reported were the Laves phase, referred to as Fe_3Nb_2 by Eggers and Peter but later amended to Fe_2Nb by Peter, and a niobium-richer compound Fe_xNb_y, details of which were left undefined.

The Laves phases are characterized by the composition A_2B. There exist three well known structural sub-divisions (Zn_2Mg, Cu_2Mg, and Ni_2Mg types) and Fe_2Nb belongs to the first (hexagonal). It is possible for the addition of a third element to bring about a change in the type of Laves phase formed; this does occur in the Cr–Nb–Si system the writer is currently investigating, but, as will be shown, not in the Fe–Nb–Si system.

The iron–niobium diagram as proposed from the present results is shown in Fig.4. The phases occurring are as follows:

Iron solution The solubility of niobium in iron is less than 2%Nb. That in α-iron decreases with decreasing temperature, and at 600°C has become virtually nil. Thus a 10%Nb (two-phase) alloy quenched from 600°C after 14 days gave an α-spacing of $\alpha_0 = 2{\cdot}8607$ kX, namely almost the value for pure iron, against $a_0 = 2{\cdot}8616$ kX for 1000°C. On quenching from the γ-region, a martensite-like state can be obtained, for instance on a 2%Nb alloy. These low-niobium alloys are thus age-hardenable and liable to show creep-resisting properties, as is in fact known. The constituent tending to precipitate is the Laves phase.

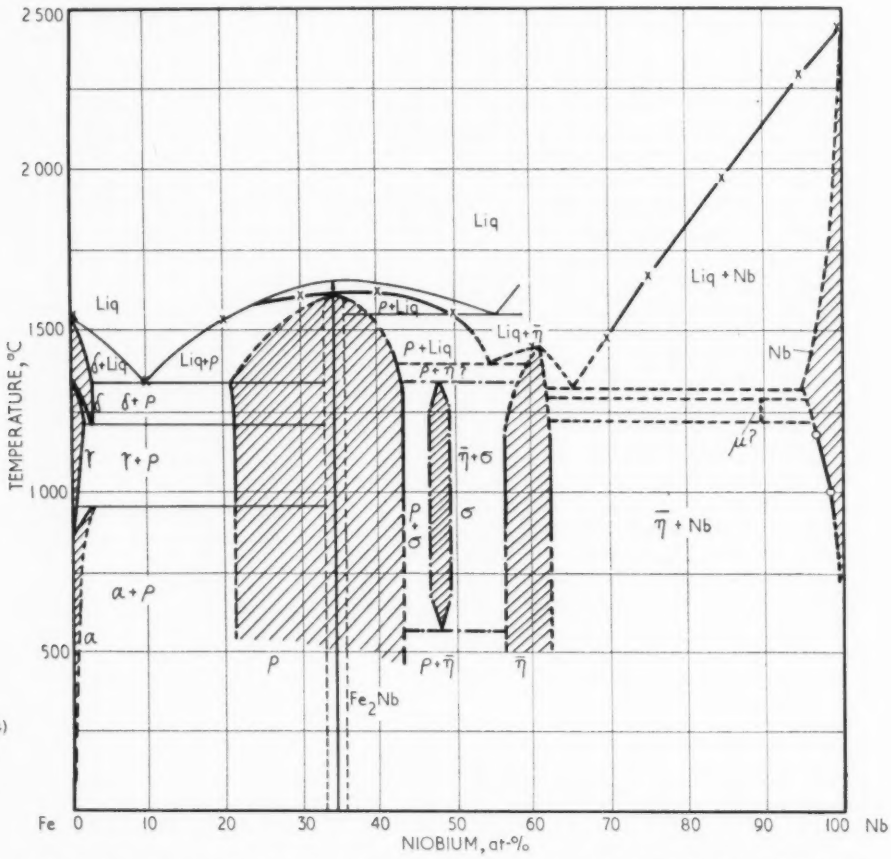
Laves phase This phase, here denoted ρ, possesses a wide homogeneity range, extending from about 22–42% niobium at 1000°C. Within this field the hexagonal lattice expands with niobium content, except for a slight qualification to be referred to later, as follows (1000°C/14 days):

20%Nb	$a = 4{\cdot}801$ kX	$c = 7{\cdot}841$ kX	$c/a = 1{\cdot}633$
30%Nb	$a = 4{\cdot}807$ kX	$c = 7{\cdot}856$ kX	$c/a = 1{\cdot}634$
40%Nb	$a = 4{\cdot}822$ kX	$c = 7{\cdot}855$ kX	$c/a = 1{\cdot}629$

Significant variations in lattice dimensions occur, however, also with heat-treatment, reflecting variations in position and manner of replacement of the Fe and Nb atoms within the Laves structure with temperature. The argument whether the previous alternative formulae Fe_3Nb_2 or Fe_2Nb apply, seems now redundant, as both are in fact covered by the present Laves-phase field.

Sigma phase A high-temperature sigma phase exists in the Fe–Nb system and is located at the approximate composition $Fe_{21}Nb_{19}$. The compound is in equilibrium with the Laves and the $\bar{\eta}$ phases (*see* below), and metastable coexistences of σ with ρ and/or $\bar{\eta}$ readily occur. The transformation $\sigma \rightarrow \rho + \bar{\eta}$ is sluggish, so that the σ-phase can be retained at room temperature, even after moderately slow cooling.

This Fe–Nb σ-phase, which is believed new, is isomorphous with FeCr, FeMo, and the various other compounds of σ-structure now known in transition-metal systems.



—Peter's result
— Present result
x Freezing points (present)
o Solubility in niobium

4 *The iron–niobium system*

Eta-carbide type phase A phase of eta-carbide type structure exists in the region of 60%Nb (denoted here $\bar{\eta}$, in distinction to $\eta=Fe_5Si_3$). This phase is likely to correspond to the compound Fe_xNb_y reported by Eggers and Peter. The prototype of the eta-carbide family is the high-speed steel carbide Fe_4W_2C/Fe_3W_3C, but many other isomorphs are now known[14–16] including intermetallic compounds without interstitial atoms, as in Ti_2Cu and Ti_2Ni.[16] The present compound should be regarded as of the latter type. The edge of the unit cube is $a_0=11{\cdot}239$ kX, but there is a small homogeneity range.

*Possibly high-*Nb *phase* At the niobium-rich end, the existence of a further high-temperature compound (μ in Fig.4) is possible, but could not be verified absolutely. The $\bar{\eta}$ phase and primary niobium are certainly in direct equilibrium at low temperatures and possibly right up to melting point. The evidence for the μ-phase is inconclusive, and verification would be required, preferably by high temperature X-ray photography.

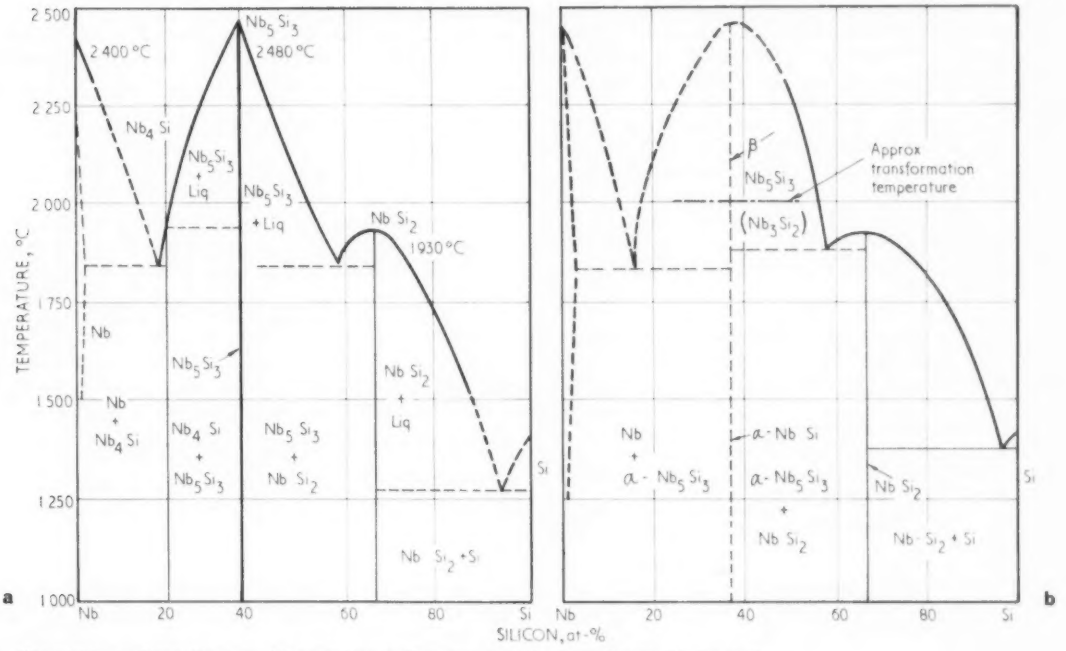
Niobium solution The solubility of iron in primary niobium is small, but important. It varies with temperature and implies a capacity for precipitation-hardening in such alloys. In view of the relative atomic sizes of Nb and Fe, the solution is no doubt substitutional. Iron addition contracts the lattice of niobium from 3·2995 kX to 3·2909 kX at 1000°C, and to 3·2845 kX at 1200°C saturation (anneal: 1 h), whilst a further contraction is observed for the as-melted ingot. Assuming these values, and a linear lattice contraction through iron, the solid solubility would be $1{\cdot}9_6$%Fe at 1000°C, $3{\cdot}4_2$%Fe at 1200°C.

Note on the lattice spacing of niobium

There appears to be a conflict regarding the lattice spacing of pure niobium. The figure generally quoted by recent authoritative sources, e.g. Wyckoff, Smithells, Hume-Rothery, and Raynor[17] and McIntosh[19] is $a_0=3{\cdot}2941$ kX. The value measured in the present investigation is 3·2995 kX at 20°C which compares with $3{\cdot}299_3$ kX found by Knapton.[18] If the former spacing value is used, the above figures for solubility in niobium would become 0·9%Fe at 1000°C, 2·2%Fe at 1200°C.

Comment on Fe–Nb *diagram*

Figure 4 does not pretend to be complete or final and the main purpose is to indicate the existence of phases and their approximate extent rather than a precise delineation. The boundaries have been determined by the disappearing phase method and from lattice-spacing variations. Vertical boundaries are based on quenches from a sequence of temperatures; e.g. an alloy 78%Fe/22%Nb (adjoining the $\rho/\alpha+\rho$ boundary) when quenched from 1000° and 1200°C (after 1 h each, the 1000°C condition agreeing with that after 14 days), showed, from spacings, a slight increase in iron-content with temperature; but for 1400°C (1 h), a closure of the single-phase ρ field is indicated by a



5 *The niobium-silicon diagram,* (a) *according to Knapton, and* (b) *according to Kieffer et al.*

lattice expansion accompanied by sharpening of diffraction lines. In contrast, an alloy 60%Fe/40%Nb (ρ pure) showed constancy with temperature, except for the appearance of a small amount of σ at 1400°C. The boundary here is defined by the presence of σ in Nb-richer alloys. The substantially vertical trend of the boundaries in the region $\rho/\sigma/\bar{\eta}$ is shown by constancy with temperature in constitution and spacing for alloys Fe/Nb:55/45 ($=\rho+\sigma$), 52·5/47·5 ($=\sigma$), 50/50 ($=\sigma+\bar{\eta}$), and 45/55 ($\bar{\eta}$+small σ). The σ-phase is bracketed fairly tightly between ρ and η, but its upper and lower temperature limits are uncertain. The essential fact here to be conveyed is that σ is a high-temperature phase, decomposing sluggishly $\sigma \rightarrow \rho+\bar{\eta}$.

Regarding the $\bar{\eta}$-phase, this was produced pure by the 1000°C/14-day treatment on alloy 40/60, whilst for seven alloys in the range 60–100%Nb, this and a 1200°C/1-h treatment yielded $\bar{\eta}$+Nb in steadily changing proportions. The equilibria at temperatures lower than 1000°C require further study. A preliminary note on the iron–niobium system has been published.[20]

The niobium–silicon system

The niobium–silicon system has been investigated by Knapton[18] and by Kieffer, Schmid, and Benesovsky,[21] whose diagrams are given in Fig.5*a* and *b*. Both agree as to the existence of the phases Nb_5Si_3 and $NbSi_2$, but Knapton found additionally the phase Nb_4Si isomorphous with Ta_4Si. A compound Nb_2Si had been reported earlier by Brauer and Scheele,[22] and its possible existence still had to be considered. The Nb_5Si_3 phase exists in two allotropic forms, α and β, stable at low and high temperatures respectively; the transformation point lies between 1900° and 2100°C, according to Knapton. A further phase with the $D8_8$ structure, of composition Nb_5Si_3 was reported by Schachner, Cerwenka, and Nowotny,[23] but this was proved by Knapton to be due to contamination by carbon. α-Nb_5Si_3 was reported to be isomorphous with Cr_5B_3 and the low-temperature form of Ta_5Si_3, β-Nb_5Si_3 with V_5Si_3, Mo_5Si_3, W_5Si_3, and the high-temperature form of Ta_5Si_3.[21] Brewer and Krikorian[24] seemed to support direct equilibrium between Nb_5Si_3 and primary niobium, Nb_4Si being absent, whilst McMurty and Crandall[25] show the presence of Nb_4Si; there is therefore contradictory evidence as to its existence.

The author's results on the niobium–silicon system, starting from the silicon-end, are as follows.

Silicon solution Niobium is insoluble in primary silicon.

Niobium disilicide $NbSi_2$ is in stable equilibrium with silicon on the one hand, and with Nb_5Si_3 on the other.

Nb_5Si_3 It is confirmed that this compound possesses two allotropic modifications. α-Nb_5Si_3 is stable up to very high temperatures; however, the high-temperature β-form can be retained to room temperature by quenching or e.g. by cooling from the melt in the arc furnace. However, whether or not β-Nb_5Si_3 is retained, depends sensitively on rate of cooling. The $\beta \rightarrow \alpha$ transformation corresponds to a spontaneous lattice-shear, unless α- and β-Nb_5Si_3 are considered as possibly of slightly different composition, implying diffusion; this, however, is not the case, as pure α and β could be produced in one and the same alloy. There exists a narrow homogeneity band of Nb_5Si_3 towards silicon.

The transformation temperature for Nb_5Si_3 is here placed at around 2000°C in agreement with Knapton. This may be exemplified by the following quenching experiments.

TABLE II Crystal structure data on binary phases entering the iron–niobium silicon system

Phase	Symmetry	Space group	Unit cell dimensions, *kX*	No. of atoms per unit cell	Remarks	References
Iron–silicon						
α (Fe–Si)-solution	Cubic (body-centred)	O_h^9–Im 3m	$a = 2{\cdot}8604$ to $2{\cdot}8076$ at Si saturation (1000°C)	2Fe to ≈1·3Fe, 0·7Si	Superlattice formed at Fe_3Si	
$Fe_2Si_3(\eta)$	Hexagonal	D_{3h}^6–$P_3$6/mcm	$a = 6{\cdot}7275$ $c = 4{\cdot}715$	16 = 10Fe, 6Si	Sometimes referred to as Fe_3Si_2 high-temperature phase only: 830–1050°C	6, 31
FeSi(ε)	Cubic (NaCl, distorted)	T^4-$P2_13$	$a = 4{\cdot}4790$	8 = 4Fe, 4Si	Present value $a = 4{\cdot}472$kX	6, 32
$FeSi_2(\zeta)$	Tetragonal		$a = 2{\cdot}68$ $c = 5{\cdot}12$	6 = 2 Fe, 4Si	Small solubility for Si Present values $a = 2{\cdot}82$ $c = 5{\cdot}04$ (Redetermination of structure desirable)	9
Si	Cubic (diamond type)	O_h^7–Fd3m	$a = 5{\cdot}4198$	8Si		
Iron–niobium						
$Fe_2Nb(\rho)$	Hexagonal (Laves phase $MgZn_2$ type)	D_{6h}^4–$P6_3$/mmc	$a \approx 4{\cdot}801$ to $4{\cdot}822$ $c \approx 7{\cdot}841$ to $7{\cdot}855$	24 = ≈19Fe, 5Nb to ≈4Fe, 10Nb	Wide homogeneity range (*see* text)	33, 35, 20
≈FeNb(σ)	Tetragonal (σ-phase)	P4/mnm		30 = 16Fe, 14Nb	High-temperature phase only	36, 42
$\approx Fe_2Nb_3(\eta)$	Cubic (η-carbide type)	Fd 3m	$a = 11{\cdot}239$	96 ≈ 40Fe, 56Nb		43, 14, 44, 16, 20
Nb	Cubic (body-centered)	O_h^9–Im3m	$a = 3{\cdot}2995$ to $3{\cdot}2909$ at Fe saturation to $3{\cdot}304$ (1000°C) at Si saturation	2Nb		
Niobium–silicon						
Nb_4Si	Hexagonal				High-temperature phase (*see* text) isomorphous with Ta_4Si	45, 46, 18
α-Nb_5Si_3 (low-temp. form)	Tetragonal	D_{2d}^{11}	$a = 6{\cdot}557$ $c = 11{\cdot}860$	32 = 20Nb, 12Si	Isomorph to $Ta_5Si_3(a)$, Cr_5B_3 (formula Nb_3Si_2 sometimes given, but superseded by Nb_5Si_3. Occurrence of $D8_8$ structure reported but disproved)	47, 48
β-Nb_5Si_3 (high-temp. form)	Tetragonal	D_{4h}^{18}–I4/mcm	$a = 9{\cdot}998$ $c = 5{\cdot}062$	32 = 20Nb, 12Si	Isomorph to $Ta_5Si_3(\beta)V_5Si_3$, Cr_5Si_3, Mo_5Si_3, W_5Si_3	
$NbSi_2$	Hexagonal	D_6^4–$C6_22$	$a = 4{\cdot}785$ $c = 6{\cdot}576$	9 = 3Nb, 6Si	Isomorph to $CrSi_2$	26, 50

The melting point was here observed at 2490°C:

Quenched from melt: (>2490°C) β pure
Quenched from melt: 2430°C β: 50%, α 50%
Quenched from melt: 2110°C β: 50%, α 50%
Quenched from melt: 1890°C: α pure

A metastable two-phase condition can thus be maintained, and even be retained, for example on annealing β-Nb_5Si_3 for prolonged periods, at 1200°C. Nb_4Si This compound certainly exists, and is isomorphous with Ta_4Si. However, it is found that Nb_4Si is a high-temperature phase only, and decomposes at lower temperatures according to the reaction $Nb_4Si \rightarrow Nb + Nb_5Si_3$.

Alloys which were Nb_4Si in the as-melted ingot (melting point 1930°C), were still Nb_4Si after annealing for 3 h at 1800°, 1400°, 1300°, 1200°C, followed by quenching, but became $Nb + \alpha\text{-}Nb_5Si_3$ at 1000°C and 1100°C after fourteen days. These findings are in full agreement with recent independent work of Knapton[27] who showed that Nb_4Si is stable at temperatures above about 1400°C. An unusual effect was found here, in that Nb_4Si tends to become stabilized in the presence of excess niobium. If, however, excess silicon is present, the same treatment (1000°C/14 days) leads to the Nb–Nb_5Si_3 decomposition.

The Nb_4Si *problem* The problem of Nb_4Si and its stability is a highly complex one. There are even indications that the compound may exist in more than one high-temperature form, and it is important to consider the existence of allotropy in the associated Nb_5Si_3: the presence at the reaction temperature of either α- or β-Nb_5Si_3 would sensitively affect the rate of formation or decomposition of Nb_4Si. It is noted that the freezing point of Nb_4Si (1930°C) is of the same order as the β-α transformation point in Nb_5Si_3 (1900/2100°C). Thus Nb_4Si may form by reaction between niobium-rich liquid on the one hand and either β or β-Nb_5Si_3 on the other; which of these alternatives is operating may be an important factor in determining formation or otherwise of the Nb_4Si structure. Also according to Knapton, Nb_4Si once decomposed, cannot be re-formed by solid reaction, only by re-melting; although the existence of Brauer and Scheele's[22] compound Nb_2Si (with two modifications) is now improbable, this does further emphasize the ambiguities in this part of the system.

Considering the place of niobium within the family of Group IV, V, VI metals, the silicides now known or reported may be summarized as follows:

Titanium	Vanadium	Chromium
Ti_5Si_3, TiSi, $TiSi_2$	V_3Si, V_5Si_3, VSi_2	Cr_3Si, Cr_5Si_3, CrSi, $CrSi_2$
Zirconium	Niobium	Molybdenum
Zr_4Si, Zr_2Si, Zr_3Si_2, Zr_4Si_3 Zr_6Si_5, ZrSi, $ZrSi_2$	Nb_4Si, Nb_5Si_3, $NbSi_2$	Mo_3Si, Mo_3Si_2, $MoSi_2$
Hafnium	Tantalum	Tungsten
Hf_5Si_3, HfSi, $HfSi_2$	Ta_4Si, Ta_2Si, Ta_5Si_3, $TaSi_2$	W_3Si_2, WSi_2

Some of these compounds form peritectically and their nucleation can be inhibited; others are high-

temperature phases only, or may be unstable. In the light of electron structure of the transition metal compounds, niobium *vis-à-vis* silicon is quite liable to show a varying inclination towards the behaviour of its neighbours depending on treatment, so that formation of metastable equilibria might readily be possible.

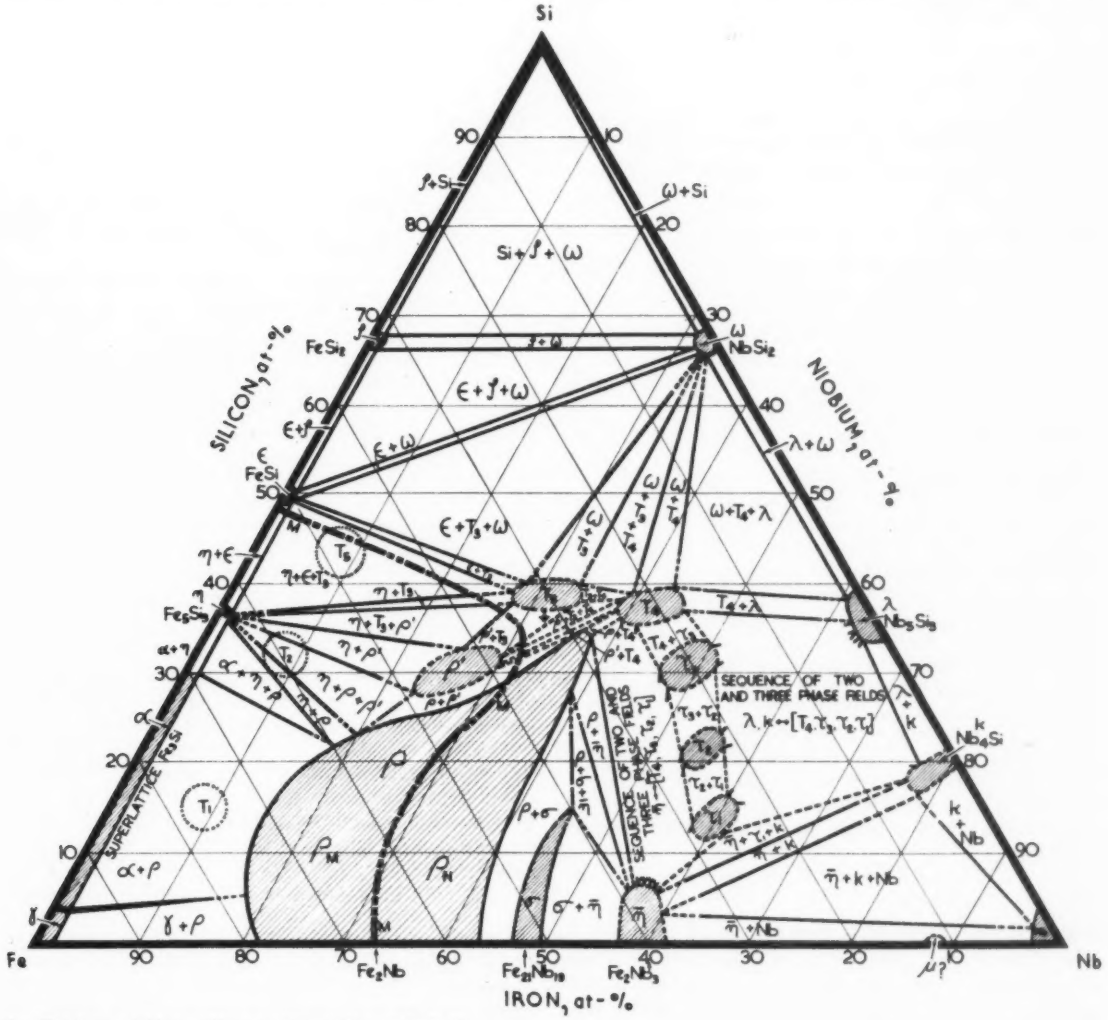
Niobium solution Primary niobium dissolves up to about 3 at-%Si at 1000°C; the solubility changes with temperature, so that the conditions for precipitation hardening are fulfilled. The evidence for this comes from alloys annealed at 800°C (8 weeks), which yield an Nb spacing smaller than for 1000°C, whilst samples quenched from 1200°C (after 1 h) and as-melted ingots give larger spacings. At a given temperature, the niobium lattice expands on silicon-addition from 3·2995 kX (Nb) to 3·304 kX, for 1000°C. This compares with Knapton's[18] expansion from $3{\cdot}299_3$ to $3{\cdot}308_3$ kX for compacts sintered at 1300°C.

The fact that niobium dissolves silicon interstitially, has been confirmed by density, combined with lattice-spacing measurements. It is believed, however, that interstitial solution can reasonably be deduced from lattice-dimensions alone. Thus, in the case of the solution of Si in Fe, which is known to be substitutional, lattice-contraction occurs; if therefore Si were dissolved substitutionally in Nb (which has the larger atom than Fe, both metals being BCC), the lattice might be expected to contract even more. In fact, however, the Nb lattice is expanded by Si, and it cannot be envisaged how this could occur substitutionally, unless some quite exceptional electronic changes were assumed. Interstitial solutions in Nb are of course well known and always associated with lattice-expansion, so that it is not unusual to find it in the case of silicon.

Crystal structures of binary phases

The crystal structures of the foregoing binary phases are summarized in Table II, as far as data are available.

Amongst niobium silicides, the $D8_8$ structure has also been reported to occur for the composition Nb_5Si_3, but it is now certain[19, 24, 28, 29, 30] that this so-called Nowotny-phase requires small quantities of



6 *The iron–niobium–silicon system, section at 1000°C*

Table III Approximate interplanar spacings of ternary Fe–Nb–Si compounds

T_3	T_4	ρ'	τ_3	τ_2	τ_1	T_1	T_2	T_5
3·58 VW	3·60 M	2·39 S	2·39 M/S	2·86 W	2·43 S	3·3 M	4·2 W	2·75 M
3·27 M	3·11 W	2·25 M/S	2·29 M	2·78 W	2·34 S	2·59 M	3·23 M	2·49
3·11 W	3·08 W	2·19 S	2·13 S	2·60 W/M	2·08 M	2·33 W	2·96 M	2·31 M/S
2·37 S	2·97 W	2·09 W	2·01 W	2·44 W	1·97 M/S	2·18 S	2·84 S	2·25 S
2·35 W	2·86 W	2·01 S	1·69 W	2·39 S	1·64 M	1·88 M	2·38 M	2·12 M/S
2·25 S	2·60 W	1·90 M	1·52 M	2·30 S	1·54 W	1·71 W/M	2·39 S	2·03 S
2·23 M	2·57 M	1·84 W	1·34 M	2·14 M/S	1·44 S	1·57 M	2·09 M	1·56 M
2·00 M	2·48 W	1·57 M	$1·32_5$M	2·08 M	1·34 M	1·38 W/M	1·63 M/S	1·43 W
1·99 W	2·39 W/M	1·48 W/M	1·30 M	1·97 W/M	1·26 S	1·34 S/M	1·34 S	1·41 M
1·91 W	2·35 W	1·45 W/M	$1·24_5$ M	1·93 M	1·165 S/M	1·31 M	1·28 W	1·31 M
1·83 M	2·25 S	1·42 M	1·13 M/S	1·86 W	1·12 S	1·27 W/M	1·08 W/M	1·16 M
1·79 W	2·22 M	1·39 M		1·79 M	1·062 S/M	1·14 M		1·078 W
1·58 W	2·16 W	1·34 S		1·74 W		1·095 M		
1·56 W	2·11 M/S	1·31 M		1·67 W				
1·45 W	2·06 W/M	$1·27_5$ M		1·63 M				
1·42 M	1·93 W	1·24 M/S		1·56 M/W				
1·40 W	1·91 M	1·19 M		1·52 W				
$1·39_5$ W	1·86 W	1·16 W/M		$1·47_5$ M				
1·35 W	1·78 W	1·14 S		1·44 M				
1·28 W	1·69 W	$1·12_5$ M		1·39 S/M				
1·27 M	1·50 M	1·115 M		1·34 S/M				
1·16 M	1·42 W	1·095 S		1·32 M				
1·125 W/M	1·38 S			$1·29_5$ M				
1·077 W/M	1·35 S			$1·27_5$ W				
	$1·30_5$ S/M			1·26 M				
	$1·27_5$ M			1·21 W				
	$1·26_5$ M			1·18 W				
	1·23 W			1·17 W				
	$1·19_5$ M			1·12 W/M				
	1·17 M							

Intensities: S = Strong, M = Medium, W = Weak.

contaminating atoms to be present, namely carbon, nitrogen, boron, and possibly oxygen. A phase of $D8_8$ structure did not occur in the present ternary system, except in Fe_5Si_3.

The ternary field

The ternary diagram derived for the Fe–Nb–Si system is shown in Fig.6. As might be expected from the component binary systems, it is of a high degree of complexity. Certain details should still be considered as tentative, especially in the niobium-corner, in view of the tendency in several regions towards metastable equilibria and sluggish transformations (*see* also comments below). The principal results are as follows:

Phases occurring and solubilities

α Iron–silicon This phase dissolves small but significant amounts of niobium, a second phase (ρ) being introduced by the addition of, at the most, 1 at-%Nb. Niobium causes an appreciable lattice expansion of α Fe–Si, as compared with binary alloys of equal silicon content. For example, at 20%Si the body-centred cube expands from $a_0 = 2·8329$ kX for 0%Nb to 2·8384 kX for 2·5%Nb (two-phase alloy). The solubility of Nb in α Fe–Si decreases with decreasing temperature, as on the Fe–Nb binary side. This is shown by a decrease in α spacing on annealing $\alpha+\rho$ alloys at 800°C (for eight weeks) as against the standard 1000°C anneal, whilst the as-melted ingot gave larger spacings. It may be possible therefore to precipitation-harden such alloys near the solution boundary.

The Fe_3Si type superlattice is maintained in the presence of niobium.

Iron-silicides The three iron-silicides Fe_5Si_3, FeSi, and $FeSi_2$ show no significant solubility for niobium.

Laves phase The iron-niobium Laves phase (ρ) possesses a very extensive solubility for silicon (*see* Fig.6). It increases with niobium content up to about 25%Si at about 38%Nb, then abruptly ceases in favour of σ, $\bar{\eta}$, and ternary phase equilibria. Further details on the ternary Laves phase will be given later.

σ-phase The iron–niobium σ-phase also has a considerable but lesser solubility for silicon, up to about 15%Si co-existing with ρ and $\bar{\eta}$.

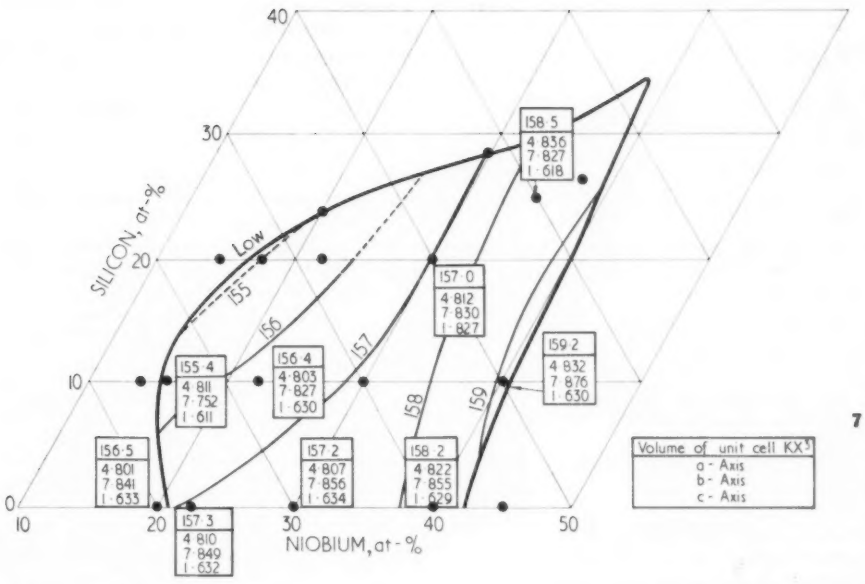
$\bar{\eta}$-phase This phase also dissolves significant amounts of silicon, but less than ρ or σ; the limit is uncertain.

Niobium The joint ternary solubility of iron and silicon in niobium metal is small but significant, as is the case for the binary Nb–Fe and Nb–Si alloys. It has not been determined quantitatively, but is in the order of 1–5 at-%. On both the binary sides it has been proved that the solubility of both Fe and Si in Nb decreases with decreasing temperature, and the same (and therefore precipitation-hardenability) is likely to apply to the ternary solution.

Niobium silicides The niobium silicides dissolve little if any iron, except for Nb_4Si, which takes a significant amount into solution. Regarding Nb_5Si_3, it is of interest that iron stabilizes the high-temperature β form, in favour of α, β-Nb_5Si_3 appearing in a number of ternary alloys which, for equivalent silicon content and treatment (1000°C/14 days), had on the binary side, given α.* There is also a suggestion that the ternary compound T_4 is structurally closely related to β-Nb_5Si_3.

Ternary compounds At least six, possibly nine, ternary compounds exist in the Fe–Nb–Si system, here denoted by ρ', T_3, T_4 (<50%Nb) and τ_1, τ_2, τ_3 (>50%Nb). Three further compounds T_1, T_2, and

* It is significant that in the investigation on the ternary system Cr–Nb–Si currently proceeding, it was found that chromium possesses a wide solubility in Nb_5Si_3, also stabilizing the β-structure.



7 *Ternary Laves-phase region in the iron–niobium–silicon system showing lines of constant lattice dimensions*

T_5 may exist, but form only sluggishly. The approximate positions of these compounds are shown in Fig.6.

The ρ' phase is so called, because its powder photograph closely resembles that of the Laves phase (ρ); however, it is not one of the two other known Laves phase (Cu_2Mg or Ni_2Mg) types. The ρ' phase is located in the hollow at the Si-rich end of the ρ region, so that the two regions in conjunction would present a substantially constant saturation limit for silicon in the Laves phase or its derivative.

In more general comment on Fig.6, it is emphasized that the essential intention is to register in this diagram the existence and equilibria of the ternary phases, whilst the determination of their exact positions and boundaries must be the subject of further work; for this reason it was decided to mark the ternary phases here schematically and without detailing the boundary shapes (as would of course be required by phase-rule considerations). Similarly the complex network of adjoining two- and three-phase fields has partly been omitted or merely shown tentatively. The fact that the ternary compounds have not necessarily been isolated in the pure state makes measurement of interplanar spacings in some cases difficult, but they have been determined and included in Table III.

The crystal structures of these new ternary silicides have not been determined, but several seem of considerable basic interest; a structure determination on T_3 is being undertaken by Mr J. A. Brand. Regarding this phase, further work has indicated a displacement towards lower silicon contents, so that, in the as-melted state, the composition includes FeNbSi. This complex central portion of the diagram particularly invites further study.

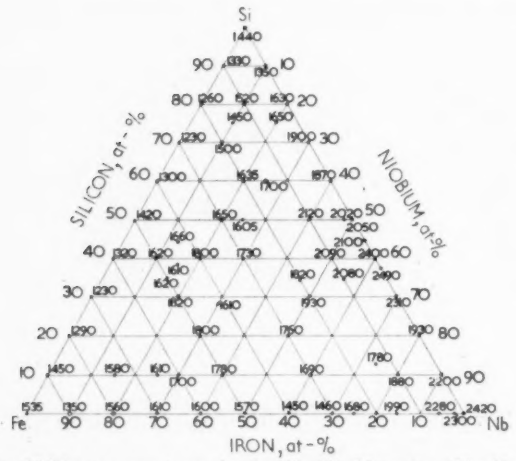
Compounds T_1, T_2, and T_5 are erratic in their appearance, and may well be metastable transition phases which should not find a place in the equilibrium diagram or which correspond to a higher temperature; in Fig.6 their existence has therefore merely been noted, the stable assemblies being those of the phase-fields as drawn; T_1 occurs together with α and ρ in an alloy within the otherwise well established $\alpha+\rho$ region; T_2 is observed in conjunction with α Fe–Si and η (Fe_5Si_3) and considering that η is itself a high-temperature phase (readily suppressed or retained as alternative to $\alpha+\epsilon$ assemblies, cf. Fig.2), T_2 might present a similar case on Nb-addition. Compound T_5 co-exists with ϵ (FeSi) and tends to intervene in an otherwise well established $\epsilon+T_3$ field; it, too, may be a restricted higher temperature phase.

Two- and three-phase equilibria

The two- and three-phase assemblies derived may be seen from Fig.6. Special features are the existence of an extensive $\alpha+\rho$ field, and the great simplicity of the silicon-corner of the diagram, in contrast to the complexity of the rest. Across the ternary diagram there exist two pseudo-binary sections $FeSi_2 \rightleftarrows NbSi_2$ and (with some allowances in stoichiometric ratio) $Fe_5Si_3 \rightleftarrows T_3 \rightleftarrows T_4 \rightleftarrows Nb_5Si_3$; it would be of considerable interest to follow through the structural transition of the latter series, which it is hoped to do. The niobium-rich Fe–Nb μ phase (which is in any case doubtful), is inhibited in the ternary diagram through Nb–$\bar{\eta}$–Nb_4Si assemblages.

The ternary Laves phase

The ternary Laves phase field is of interest in showing considerable variations in lattice dimensions with Fe, Nb, and Si content. Values are given in Fig.7. Other single-phase alloys were available as marked, but line-broadening vitiated accurate measurement in these cases. The relationship between the a and c axes and composition appears irregular, except for the general trend to expand with niobium content. However, on evaluating the unit cell-volumes ($V=\sqrt{3}\,a^2c$), a consistent picture emerges, as shown in Fig.7. Niobium steadily expands the volume, slowly and with a plateau near the iron–niobium side, steeply for higher silicon contents. It seems that in the Laves phase the



8 *Melting temperatures in the Fe–Nb–Si system (liquidus approximate values only)*

silicon atoms can be dissolved partly substitutionally, as in pure iron, partly interstitially, as in pure niobium, and although the axes of the unit cell may change irregularly, this is rectified by the steady change of total unit-cell volume. Varying heat-treatment and relatively minor changes in the Fe/Nb/Si ratio may cause a spontaneous and major redistribution of atoms over the sites available in the unit cell. This is also reflected by changes in X-ray line intensity observed for alloys within the single-phase field, and the above-mentioned line broadening similarly indicates that, even within a given pure Laves phase sample, lattice strains can occur through the variations in atom positions.

These subsidiary changes within the ternary Laves phase present a problem worth pursuing. A further observation is here of interest: a given alloy situated near the $\rho/\rho+\sigma$ boundary can be produced either as the pure Laves phase, or accompanied by sigma phase. When two-phase, the lattice-dimensions were larger than when single-phase. The sigma phase precipitating from Laves phase therefore is richer in silicon than the parent. As a counterpart of this, it may be noted that silicon contracts both σ and the $\bar{\eta}$ phase, indicating that it replaces iron in both cases.

PROPERTIES OTHER THAN CONSTITUTIONAL

Ferromagnetism

It was noted that some pure Laves phase alloys were magnetic, others not, and it appeared of interest to examine all present alloys from this aspect. It was found that a sharply defined boundary exists dividing magnetic from paramagnetic alloys. This is shown by line M–M in Fig.6. The line divides the Laves phase field into two portions, ρ_M and ρ_N; this boundary follows roughly a line of constant unit-cell volume, namely the contour for $V \approx 157{\cdot}5$ kX^3 in Fig.7. The α, η, ρ_M, and ρ' phases are ferromagnetic, all others not. The boundary M–M is the same, whether determined on alloys as-melted, or as-annealed at 1000°C for 14 days.

Melting points

The melting temperatures of many of the present alloys have been determined in the argon arc furnace, using an optical pyrometer and the known melting points of pure metals for calibration. The results are given in Fig.8. The temperatures correspond to the liquidus, but the approximate nature of the values should be emphasized. The experimental error is believed to be about ±15°C. There is, however, very satisfactory agreement of results with known liquidus or eutectic points, such as those published for the Nb–Si[18] and the Fe–Nb[11] systems. For the ternary Laves and ρ' phases a peak temperature of more than 1800°C is attained, but there are also pronounced eutectic troughs. Apart from this and the high values for niobium, Nb_5Si_3, $NbSi_2$, and some adjoining alloys, the melting points in the ternary system do not reveal any outstanding features.

TABLE IV Oxidation resistance of some iron–niobium–silicon alloys to air at 1000°C for 1 h

Alloy composition, At-% Fe	Nb	Si	Gain in weight on oxidation, mg/cm^2	Scale constitution
Elements				
...	100	...	63	β Nb_2O_5
100	...	...	27	$FeO/Fe_3O_4/Fe_2O_3$ (layered)
...	...	100	3	...
Nb–Si binary				
...	97	3	172	Nb_2O_5: β large, α small
...	90	10	130	Nb_2O_5: β large, α medium
...	80	20	102	Nb_2O_5: β small/medium, α large
...	60	40	80	Nb_2O_5: β small α large (Alloy = Nb_5Si_3; *see* text)
...	30	70	1·1 (N at 800°C)	Nb_2O_5: α only
Nb–Fe binary				
10	90	...	49	Nb_2O_5: β
40	60	...	5	V_2O_5 type
50	50	...	8	V_2O_5 type
60	40	...	4	V_2O_5 type, converting to zircon type at 1200°C
70	30	...	3·5	V_2O_5 type + Fe_2O_3
80	20	...	2·2	$Fe_2O_3 + V_2O_5$ type
90	10	...	12·5	Fe_2O_3 + spinel (Fe_3O_4) + V_2O_5 type, trace
90	...	10	8·0	Fe_2O_3 + spinel (Fe_3O_4) small
75	...	25	1	Spinel (Fe_3O_4)
62·5	...	37·5	N*	} Thinnest film only
50	...	50	N*	
33·3	...	66·7	N*	
Ternary				
10	80	10	154	Nb_2O_5: β large α small
2	79	19	111	...
2	61	37	4	...
20	55	25	28	V_2O_5 type
35	55	10	D	V_2O_5 type
10	40	50	E	Nb_2O_5: β small α large
20	40	40	E	...
50	40	10	2·0	V_2O_5 type
40	30	30	2·2	V_2O_5 type
40	25	35	2·0	...
25	25	50	3·1	...
5	20	75	N*	} Thinnest film only
55	20	25	N*	
63	17	20	4·9	...
20	10	70	N	Thinnest film only
45	2	53	1·9	...
78	2	20	1·0	Spinel (Fe_3O_4)

α-Nb_2O_5 is the low, β-Nb_2O_5 the high-temperature form
N = Negligible oxidation
* = Oxidation still negligible aftre 16 h at 1000°C and at 1100°C
D = Disintegrated
E = Erupted

The help of Mr R. Smith and Dr D. Eccleston in carrying out the oxidation measurements is gratefully acknowledged

Oxidation resistance

The measurement of resistance to oxidation of Fe–Nb–Si alloys at high temperatures was included partly for its evident practical interest, but also for the more fundamental reason that it allows the study of the oxide layer formed and an attempt to correlate this with degree of protectiveness. In the present exploratory tests the increase in weight per unit surface area for specimens exposed at 1000°C for 1 h in still air, was used as a measure; higher temperatures and longer times were used in some cases.

The results are shown in Table IV. It may be seen that the oxidation resistance of the alloys varied between extreme limits, as follows:

Binary alloys

Niobium and alloys rich in niobium show very poor oxidation resistance, as is to be expected. Addition of silicon initially causes a deterioration, but some recovery occurs towards Nb_5Si_3, great improvement towards $NbSi_2$. Addition of iron, on the other hand, gives increased oxidation resistance on both $\bar{\eta}$ and ρ phase formation. Occurrence of σ phase between $\bar{\eta}$ and ρ, is associated with a small drop.

Iron–silicon alloys show good oxidation resistance even at low silicon contents, and are comparable in quality with niobium–silicon alloys at the high-silicon end. Of the two disilicides, $FeSi_2$ is superior to $NbSi_2$.

Ternary alloys

Ternary alloys rich in niobium have very low resistance. With reduced niobium content however, certain ternary areas occur where oxidation resistance becomes excellent. For example, as little as 2% iron added to Nb_5Si_3 gave considerable improvement.

Favourable behaviour is found, (*a*) in regions covering the silicon-saturated Laves phase and certain of the adjoining silicon-richer compounds; (*b*) in iron–silicon base alloys low in niobium, containing α-ferrite, η, and ϵ, associated with ρ, ρ', or T_3; (*c*) in disilicide base alloys of the region $NbSi_2$+$FeSi_2$, with the possible entry of the ternary compounds T_3 and T_4.

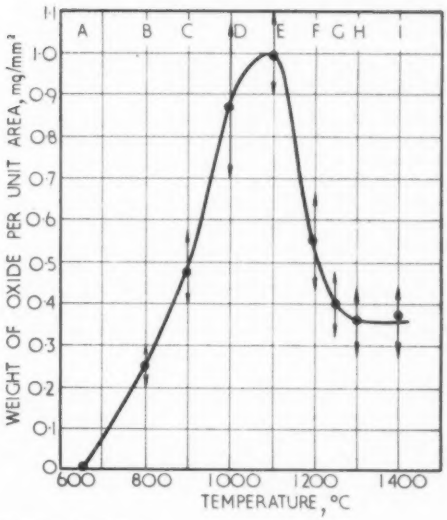
The phases $\bar{\eta}$, σ, and the Nb-richer ternary compounds are inferior; so is Nb_5Si_3, but an observation should here be mentioned, believed of some fundamental interest in developing heat-resisting alloys of the present type.

This will be reported in the appendix, which also contains brief comments of the results on scale constitution.

SUMMARY AND CONCLUSIONS

The survey of the Fe–Nb–Si diagram at the 1000°C section shows a highly complex system of phase-assemblages, involving 15 binary, and at least six, possibly nine, ternary compounds. Some features of interest are (*a*) the extensive solid solution of silicon in the iron–niobium Laves phase; (*b*) the small but finite solubility of niobium in iron–silicon solid solutions, which should promote precipitation-hardening; (*c*) the occurrence of a sigma phase and its solution of silicon; and (*d*) the relative simplicity of the silicon corner, in contrast to the rest of the diagram.

The system suggests many interesting subjects for possible further work, in particular study of the crystal structures of some of the new compounds, the problems of Nb_4Si stability and of formation of some of the ternary compounds. The extent of certain phase fields, their equilibria and their change with temperature also await further investigation. Melting points and oxidation resistance, in conjunction with constitution, indicate features of practical interest, and several alloy areas suggest themselves for development and possible use in heat-resisting alloys (not excluding of course the use of additional elements or of binders). Oxidation resistance, which appears promising in certain regions, should be viewed in the light of oxide structures formed. The limitations of the alloys, in particular those set by brittleness, must however be realized.



Scale constituents
A α-Nb_2O_5
B β-Nb_2O_5

9 *Degree of oxidation of alloy Nb_5Si_3 after 1 h at temperature*

ACKNOWLEDGMENTS

The writer expresses his sincere thanks to Mr D. A. Oliver, C.B.E., Director of Research, The BSA Group Research Centre, for his encouragement and interest, and to Mr J. A. Brand for valued assistance.

APPENDIX

OBSERVATIONS ON OXIDATION RESISTANCE OF Fe–Nb–Si ALLOYS

Improvement with temperature

The remarkable effect found was that the oxidation resistance of Nb_5Si_3 could be greatly improved at increased temperatures, severe attack at 1000°C becoming slight only at 1200°C under otherwise constant conditions. Quantitative results are shown in Fig.9. The effect goes in parallel with structural changes observed in the oxide constitution. Nb_2O_5 was the sole crystalline oxide throughout, but a phase transformation occurs from low temperature (α) to high temperature (β) Nb_2O_5. The X-ray results, showing the manner of this phase-change on the actual test specimens, are given in Fig.9, alongside the oxidation curve. The improvement in protection is accompanied by the transition to the pure β-form. An amorphous siliceous phase, however, enters additionally.

A fuller investigation on these and other phase transformations in niobium-bearing oxides is proceeding and will be

reported separately. Part of this has recently been published.[51]

Scale constitutions on Fe–Nb–Si alloys

Referring to Table IV, a first correlation between oxidation behaviour and constitution of the oxide produced brings out the following.

Whilst Nb_2O_5 always gives poor protection, both in its high and low temperature forms, the two forms do show a difference. Both α- and β-Nb_2O_5 can be stabilized by different alloy additions, and it depends on lattice adaptation of the oxide to base alloy structure and on relative expansion coefficients which form is the more favourable. It would not be correct to specify that either the α- or β-Nb_2O_5 is inherently more protective, and separate work shows that both forms could in principle act protectively, subject to a variety of factors.

The V_2O_5 type structure can be induced by iron and silicon addition, in some cases with considerable improvement, as exemplified by Table IV.

It is of interest that in Laves phase alloys the oxide can show the zircon-type structure besides the V_2O_5 type; considering that the zircon structure is characteristic of numerous vanadates (mostly incorporating rare earths, such as $ErVO_4$, $GdVO_4$, etc), the formation of isomorphous niobates seems an analogous case, though not hitherto reported. (This aspect of the investigation is being extended by the addition to Nb_2O_5 of various other oxides, which shows that, under varied conditions, the rutile, spinel, niobite, hematite, and other types of structure can be stabilized, taking over from the Nb_2O_5 structures at definite compositions and for definite heat-treatments.)

In some cases of oxidized Fe–Nb–Si alloys the apparent oxide scale in fact consists of disintegrated particles of the base alloy proper (e.g. Laves phase), as shown by X-ray examination; a very thin oxide film along the grain boundaries will here have formed, and alloys of this type should not necessarily be rejected, because such grain boundary penetration can in principle be circumvented.

Finally, for a number of the present ternary alloys good oxidation resistance continues to hold for prolonged periods at 1000°C and at temperatures of 1200°C and 1300°C; for example alloys with 69%Fe, 2%Nb, 29%Si, and with 26%Fe, 2%Nb, 72%Si showed negligible oxidation after six weeks at 1000°C.

REFERENCES

1. D. A. Oliver and G. T. Harris: *J. West Scotland ISI*, 1946–7, **54,** 97–119.
2. D. A. Oliver and G. T. Harris: *Trans. Inst. Marine Eng.*, 1947, **59,** 79–89.
3. H. J. Goldschmidt: *Metallurgia*, 1951, **43,** 157–160.
4. G. G. Mukhin and N. Yu. Pal'chuk: *Avtom Svarka*, 1957, 1–10.
5. H. J. Beattie and F. L. Ver Snyder: *Nature*, 1956, **178,** 208–209.
   H. J. Beattie and W. C. Hagel: *Trans. AIME*, 1957, **20,** 911–917; and private communication.
6. M. C. M. Farquhar, H. Lipson, and A. R. Weill: *JISI*, 1945, **152,** 457–472.
7. E. S. Greiner and E. R. Jette: *Trans. AIME*, 1937, **125,** 473–481.
8. J. L. Haughton and M. L. Becker: *JISI*, 1930, **121,** 315–335.
9. G. Phragmen: *JISI*, 1926, **114,** 397–404.
10. M. Hansen: 'Constitution of binary alloys', 1958, New York, McGraw-Hill.
11. H. Eggers and W. Peter: *Mitt. Kaiser Wilhelm Inst.*, 1938, **20,** 199–203.
12. W. Peter: unpublished report, 1945.
13. R. Genders and R. Harrison: *JISI*, 1939, **140,** 29p–37p.
14. N. Karlsson: *Nature*, 1951, **168,** 558.
15. K. Kuo: *Acta Met.*, 1953, **1,** 301–304.
16. W. Rostoker: *Trans. AIME*, 1952, **94,** 209–210.
17. R. W. Wyckoff: 'Crystal structures', 1951, New York, Interscience Publ. Inc.
    C. J. Smithells: 'Metals reference book', **1,** 1955, London, Butterworths.
    W. Hume-Rothery and G. V. Raynor: 'The structure of metals and alloys,' 1954, London, Inst. Metals.
18. A. G. Knapton: *Nature*, 1955, **175,** 730.
19. A. B. McIntosh: *J. Inst. Metals*, 1956–57, **85,** 367–372.
20. H. J. Goldschmidt: *Research*, 1957, **10,** 289–291.
21. R. Kieffer, H. Schmid, and F. Benesovsky: 2nd Plansee Seminar, 1955, 154–165.
    R. Kieffer, F. Benesovsky, and H. Schmid: *Z. Metallk.*, 1956, **46,** 247–253.
22. G. Brauer and W. Scheele, in Klemm: Z. Anorg. Chemie, 1948, **24,** (ii), 103, Wiesbaden.
23. H. Schachner, E. Cerwenka, and H. Nowotny: *Monatshefte f. Chemie*, 1954, **85,** 245–254.
24. L. Brewer and O. Krikorian: UCRL 2544, University of California, 1954.
25. C. H. McMurty and W. B. Crandall: *Amer. Ceram. Soc. Bull.*, 1956, April, 13, and private communication.
26. H. J. Walbaum: *Z. Metallk.*, 1941, **33,** 378–381.
27. A. G. Knapton: private communication.
28. E. Parthe, H. Nowotny, and H. Schmid: *Monatshefte f. Chemie*, 1955, **86,** 385–396.
29. E. Parthe, H. Schachner, and H. Nowotny: *ibid.*, 1955, **86,** 182–185.
30. H. Nowotny, B. Lux, and H. Kudielka: *ibid.*, 1956, **87,** 447–470.
31. K. Amark, B. Boren, and A. Westgren: *Svensk Kemisk Tidskrift*, 1936, **48,** 274.
32. F. Wever and H. Möller: *Z. Kristallogr.*, 1930, **75,** 362.
33. F. Laves and H. Witte: *Metallwirtschaft*, 1935, **14,** 645–649.
34. F. Laves and H. J. Wallbaum: *Z. Anorg. Chem.*, 1942, **250,** 110.
35. R. L. Berry and G. V. Raynor: *Acta Cryst.*, 1953, **6,** 178–186.
36. G. J. Dickens, A. M. B. Douglas, and W. H. Taylor: *JISI*, 1951, **167,** 27.
37. B. G. Bergman and D. P. Shoemaker: *J. Chem. Phys.*, 1951, **19,** 515.
38. J. S. Kasper, B. F. Decker, and J. R. Belanger: *J. Appl. Phys.*, 1951, **22,** 361–362.
39. C. W. Tucker jun.: *Acta Cryst.*, 1951, **4,** 425–431; and further papers.
40. J. Thewlis: *Nature*, 1951, **168,** 198–199; *Acta Cryst.*, 1952, **5,** 790–794; *ibid.*, 1954, **7,** 323–328.
41. P. A. Beck and P. Greenfield: *Trans. AIME*, 1954, **200,** 253–257.
42. H. J. Goldschmidt: *Research*, 1949, **2,** 343–344.
43. A. Westgren and G. Phragmen: *Trans. Amer. Soc. Steel Treat.*, 1928, **13,** 539–552; *Jernkont. Ann.*, 1933, **117,** 114.
44. K. Kuo: *Acta Met.*, 1953, **1,** 301–304.
45. H. Nowotny *et al.*: *Monatshefte f. Chemie*, 1953, **84,** 1–12.
    R. Kieffer *et al.*: *Z. Metallk.*, 1953, **44,** 242–246.
46. L. Brewer *et al.*: *J. Am. C.S.*, 1951, **73,** 3896–3898.
47. H. Nowotny *et al.*: *Monatshefte f. Chemie*, 1954, **85,** 255–272.
48. E. Parthe, H. Nowotny, and H. Schmid: *ibid.*, 1955, **86,** 385–396.
49. B. Aronsson: *Acta Chemie Scand.*, 1955, **9,** 1107.
50. H. Nowotny, R. Kieffer, and H. Schachner: *Monatshefte f. Chemie*, 1952, **83,** 1243–1252.
51. H. J. Goldschmidt: *J. Inst. Metals*, 1959, **87,** 235–240.

Stress corrosion of austenitic stainless steel by high-temperature solutions and contaminated steam

P. P. Snowden, A.Met.

SYNOPSIS

18–9 Nb-stabilized austenitic stainless steel has been exposed to chloride and caustic solutions ranging from 100 ppm to 75% at various stresses and temperatures. The rate of stress-corrosion attack has been found to depend not only on the level of stress present but on solution strength and temperature.

Tests have also been carried out in high-temperature, high-pressure steam with chloride- and caustic-contaminated specimens. It has been found that the attack caused by sodium and potassium hydroxides can be either inter- or transcrystalline, depending upon the conditions under which the tests are carried out.

Additions of sodium phosphate or nitrite have greatly reduced the rate of attack under all conditions of test, and it is possible that such additions may be an effective preventive measure under some operating conditions.

1691

INTRODUCTION

A RECENT REPORT[1] concerned the very rapid failure by stress corrosion of superheater tubes due to the ingress of sodium chloride during regeneration of an anion exchanger. Rapid failure of this type in the presence of chloride was discussed in a previous paper[2] dealing with the behaviour of austenitic stainless steel in high-pressure steam and hot-water systems. These earlier tests dealt more particularly with high concentrations associated with crevice concentration or solid deposits under dew-point conditions. This work has now been extended, with special reference to the quantitative effects of solution concentration, temperature, and stress, and has included solutions of caustic alkalis as well as sodium chloride of strengths ranging from 100 ppm to 75%.

The work with caustic solutions has included both sodium and potassium hydroxide, the latter being of particular interest to the metallurgy division of AERE who had experienced an unusual form of attack in an apparatus dealing with potassium hydroxide solutions of pH 10·5–11·5.[3] Some of this work has recently been briefly discussed[4] outside the present paper.

In addition to the work with plain chloride or caustic solutions and the associated tests in static steam and circulating water, a number of inhibitory substances have been tested with encouraging results.

DESCRIPTION OF APPARATUS

The tests in high-pressure steam and circulating water were carried out in apparatus previously described[2] but to carry out tests at high temperatures with solutions of known concentration it was necessary to design and build a new type of test equipment. This is shown in Fig.1 and consists of a small thick-walled pressure vessel to which the hollow specimen is clamped by means of a large nut. Details of the specimen are given in Fig.2. A recess for a thermocouple is provided in the lower portion of the specimen and a connection at the top of the pressure vessel allows pressure to be recorded and gas additions to be made. Stress is applied through a lever system with a mechanical advantage of 15:1, ball and socket joints ensuring axial loading, and a small resistance heater is used to bring the specimen to working temperature. The whole is enclosed in a steel cabinet and the capacity of the system has been kept small (about 8 ml) to minimize the effects of any possible explosion.

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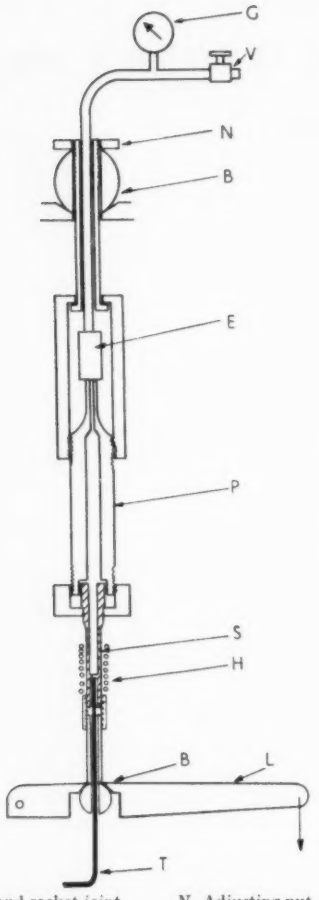
Operation of apparatus for tests with high-temperature solutions

In operation, the pressure vessel, which is also made of austenitic stainless steel to prevent any protective electrolytic effects, is filled with solution and the specimen is clamped into position, sealing on to a nickel washer. The specimen and solution container are attached to the pull-rods, after the top pressure connection is made, and the load applied; 200 lb/in^2 air pressure is added and pressure further increased with nitrogen to raise the boiling point of the solution above the working temperature. The heater is then switched on and the specimen brought to temperature. From RT to 250°C normally takes from 20 to 30 min.

Specimens were cleaned by degreasing with acetone followed by toluene and boiling in distilled water immediately before testing.

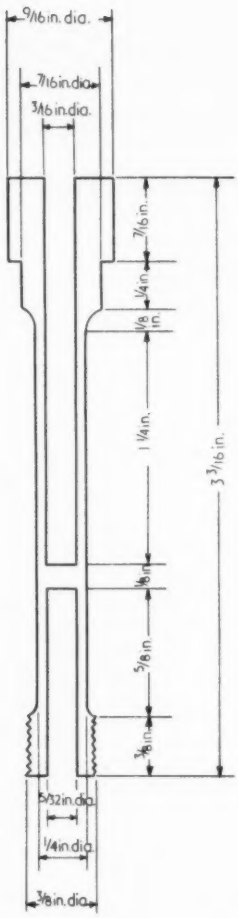
Material

All the work has been carried out on two casts of steel of the 18–9 Nb-stabilized type, the analyses and typical mechanical properties of which are given in Table I. This grade of alloy was chosen for being consistently fully austenitic.



B Ball and socket joint
E Pipe coupling
G Pressure gauge
H Heating element
L Loading lever
N Adjusting nut
P Pressure vessel
S Specimen
T Thermocouple
V Valve

1 *Diagram of apparatus*



2 *Detail of specimen*

TESTS IN CHLORIDE SOLUTIONS

From consideration of the earlier work[2] it was thought that highly concentrated solutions would be required to cause rapid attack and, accordingly, the first tests were carried out at 20 tons/in² stress and 250°C with solutions of 50 and 33 wt-% NaCl. At the working temperature these correspond to oversaturation and slightly below saturation level respectively. The oversaturated solution did not cause failure but the 33% solution resulted in extremely rapid stress-corrosion attack. The effects of progressively more dilute NaCl solutions were therefore investigated and rapid failures at temperatures in the range 200–260°C occurred down to 0·1%NaCl. Even at 100 ppm, failure occurred in 49 h. The results are detailed in Table II.

To investigate the behaviour of the steels under less onerous conditions, tests were conducted at lower stresses and temperatures and the results given in Tables III and IV obtained. For comparison the results obtained in a series of tests carried out at atmospheric boiling point are included in Table III. These tests were carried out in open vessels with no added air.

TABLE I Analyses of materials used

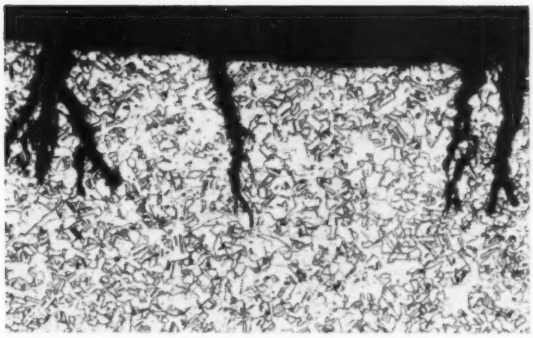
	Cast No.	Composition, % C	Si	Mn	Cr	Ni	Nb
Steel 1	01972	0·07	0·60	0·78	17·72	8·75	0·80
Steel 2	44121	0·11	0·50	0·41	17·84	9·50	1·22

Typical mechanical properties	YP tons/in²	MS	El %	R in A %
	17	40	58	65

TABLE II Effect of NaCl concentration at 20 tons/in²

NaCl, wt-%	Temperature, °C	Life, h
50	240	116 UB*‡
33	200	0·2†
20	220	1·1
10	250	1·3
6	260	7·5
6	200	0·4†
3	225	0·6
3	245	0·8
1	200	0·5†
0·1	250	0·6
0·01 (100 ppm)	250	49·4

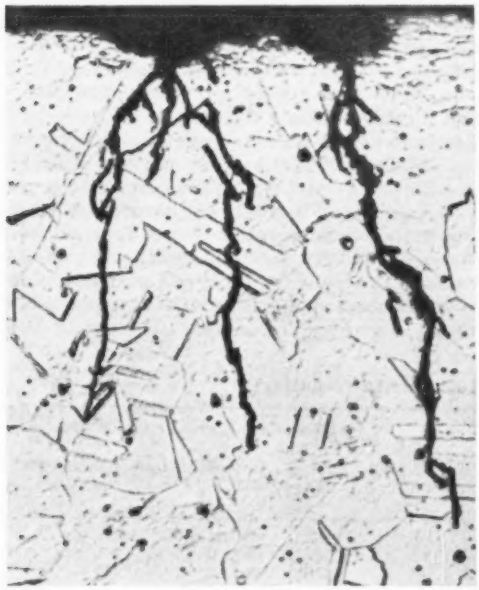
* Some cracking
† Failed during heating up
‡ UB = Unbroken



3 *Typical area of severe cracking in specimen tested at 240°C with 3% NaCl* ×100

The cracking found with most of the specimens had the transcrystalline appearance usually associated with this type of material. Figures 3 and 4 show typical areas of a specimen tested at 240°C with a 3·0% solution.

With the oversaturated solutions complete failure did not occur within the 116-h duration of the test, although it was found that some cracking had occurred. This closely resembled the type of attack suffered by chloride-coated specimens exposed to superheated steam and reported in the previous paper.[2] As will be seen from Fig.5, the cracks lack the characteristic branching appearance of stress-corrosion cracking of this alloy, being broader and stubbier with a considerable amount of corrosion product within the crack. The reduced rate of attack in oversaturated solution is also comparable with the behaviour of the salt in superheated steam and it would seem that the conditions correspond more to this than to somewhat lower concentrations. Presumably the aggressiveness of the electrolyte is reduced under these conditions, by deposition of 'dry' salt with consequent stifling of the reactions.



4 *Detail of typical smaller cracks showing transcrystalline nature of cracks in Fig.3* ×1000

TABLE III Effects of stress and concentration at 250°C and at atmospheric boiling point

Applied stress, tons/in²	NaCl, wt-%	Life, h
Tests at 250°C		
20	3	0·8
10	3	1·6
20	0·1	0·6
13	0·1	16·8
10	0·1	43·3
5	0·1	97·4
2	0·1	428·5 UB‡
20	0·01 (100 ppm)	49·4
13	0·01	1436 UB†
10	0·01	640 UB†
At atmospheric boiling point		
30	20	82
	6	985
20	20	207
	10	320
	6	1045
10	10	1484

‡ UB = Unbroken
† Some cracking

TESTS IN CAUSTIC SOLUTIONS

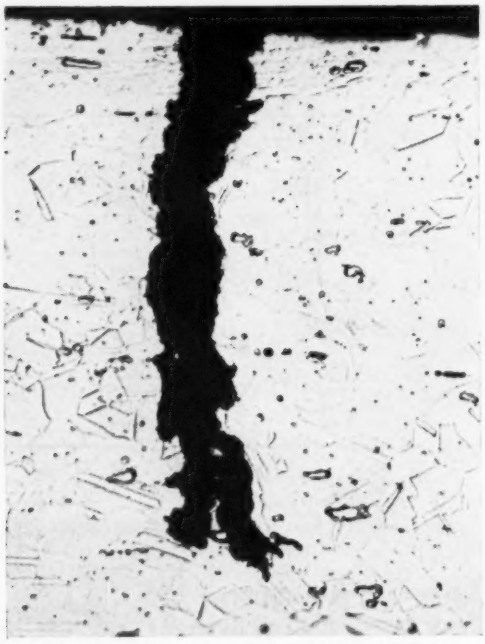
As with the chloride solutions the first tests were carried out at high concentration but in this case the first temperature investigated was 300°C, this being of immediate practical interest. A solution of 50 wt-% KOH at 300°C with an applied stress of 10 tons/in² produced failure in 8 h, the cracking being entirely intercrystalline (*see* Fig.6), and further tests, the results of which are given in Table V, were carried out with progressively more dilute solutions. The rate of attack, which even with the very concentrated solutions is less than that with chloride, is reduced as the solutions become more dilute but the nature of the cracking remains intercrystalline. Very dilute solutions of KOH seem much less damaging than chloride; a 0·1% KOH solution did not give rise to any cracking, while 0·1% NaCl produced rapid failure and even a 100-ppm solution at 10 tons/in² caused some cracking.

Reducing the applied stress or temperature again increased the life obtained, and the results of these tests are shown in Table V. Examination of numerous specimens showed that in all cases the cracking was intercrystalline but, as with chloride stress-corrosion cracking of this material, there was no general surface attack. Furthermore, the material showed no susceptibility to intercrystalline corrosion in the standard acid copper sulphate and Huey tests. The tests carried out with sodium hydroxide to compare with those using potassium hydroxide are also reported in Table V and show very similar trends to the KOH tests, life increasing with decreasing concentration, stress, and

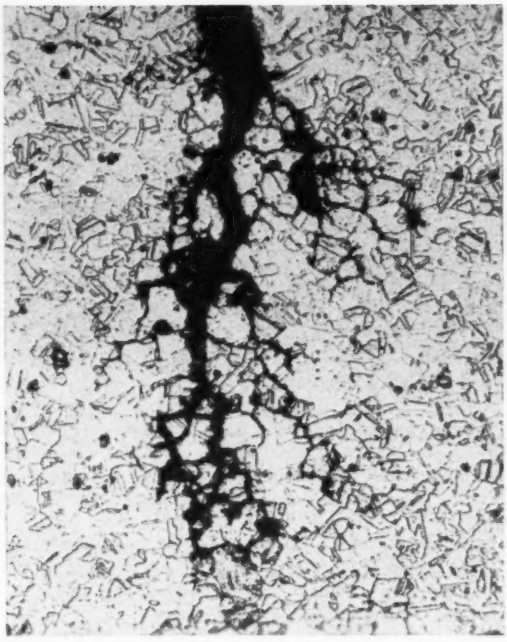
TABLE IV Effect of temperature in tests with 1% NaCl at 10 tons/in²

Temperature, °C	Life, h
250	1·5
200	27·5
170	85·0 UB*‡
150	350 UB*

* Slight cracking
‡ UB = Unbroken



5 *Cracking found with oversaturated* NaCl *solution at 250°C* ×500



6 *Intercrystalline cracking with 50%* KOH *solution at 300°C* ×200

temperature, the dependence upon stress being particularly marked in the case of NaOH. Microexamination again showed the cracking to be intercrystalline, as illustrated by Fig.7, although there appear to be more small areas of transcrystalline cracking, Fig.8, than with the potassium salt. Following these observations, further tests, described in the following section, were conducted in the high-pressure steam apparatus using specimens contaminated with either sodium or potassium hydroxide.

STEAM TESTS UNDER DEW-POINT AND SUPERHEAT CONDITIONS

The types of test discussed in this section were described in the previous paper,[2] but it will be as well briefly to describe the procedure adopted. In the dew-point test the contaminated specimen is loaded at RT, raised to working temperature, and held until increasing steam pressure results in condensation on the sample, with the formation of a highly concentrated solution. Continuing condensation dilutes the solution until contamination is entirely removed. This constitutes one cycle. With the superheat test, however, no condensation occurs, the specimen being held at a temperature above that corresponding to the maximum steam pressure attained, and the test can be continued indefinitely.

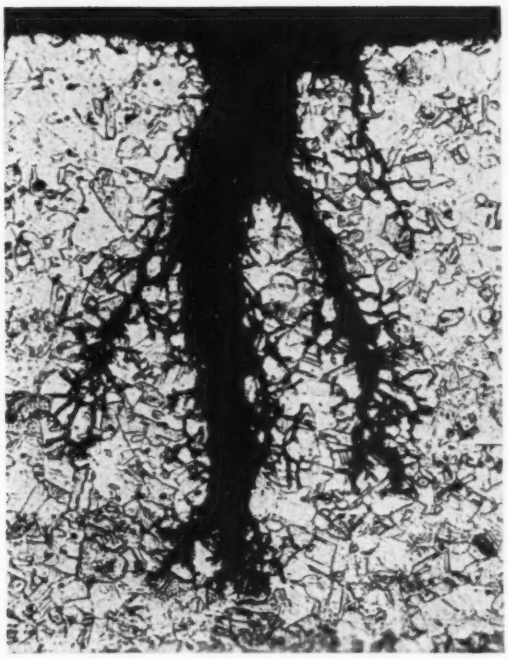
Tests were carried out under these conditions with both sodium and potassium hydroxide contamination, the sample being coated by partial immersion in either a 30% solution or the molten hydroxide before the test. The manner in which the coating was prepared had no effect on the test and for convenience the 30% solution was mainly used. The rate of attack with NaOH was found to vary greatly and to be unrelated to test temperature or steam pressure, lives from a few hours to over 100 h being obtained under similar conditions, and occasionally no attack whatever was found. Variation of the applied load, however, does influence the behaviour, considerable increase in life being obtained with lower stresses, particularly on specimens re-softened after machining. A selection of results is presented in Table VI, illustrating the variability in time to failure and effect of applied load.

Absence of oxygen due to possible leakage could be discounted as a possible cause of variability, since it had been shown previously[2] that oxygen was not necessary for stress corrosion in the case of caustic

TABLE V Effects of concentration, stress, and temperature with KOH and NaOH solutions

Effect of concentration at 300°C and 10 tons/in²			Effect of stress at 300°C			Effect of temp. with 10 tons/in² stress		
Wt-%	Life with KOH, h	Life with NaOH, h	Applied stress, tons/in²	Life with 20% KOH, h	Life with 20% NaOH, h	Temp., °C	Life with 20% KOH, h	Life with 20% NaOH, h
50	7·8	2·1	20	2·0	...	300	3·8, 19·8	1·1, 1·8
20	3·8, 19·8	1·1, 1·8	10	3·8, 19·8	1·1, 1·8	250	12·2, 55·7	3·6, 1·6
5	51·2, 17·6	6·4, 15·1	7·5	... ...	137	200	40·8, 82·6	177·8
1	17·9, 150 UB‡		5	16·9, 30·3	112, 118	175	43·7, 195·8	
0·1	551 UB‡		2	28·5, 88·5	400 UB‡	150	500 UB‡	

‡ UB = Unbroken



7 *Intercrystalline cracking with 50% NaOH solution at 300°C* ×200

8 *Inter- and slight transcrystalline cracking with 5% NaOH solution at 300°C* ×500

soda. It was thought that variations in the temperature at which the load was applied might have been responsible, but a few tests carried out with sodium hydroxide and also with sodium chloride, in which the stress was applied above RT, gave inconclusive results.

Micro-examination of numerous specimens showed that the cracking produced with NaOH under steam conditions differed from that in the solution tests. Some slight intercrystalline tendency was present, but as Fig.9 shows, the appearance of the cracks closely resembles the 'typical' transcrystalline cracking of these alloys due to chlorides.

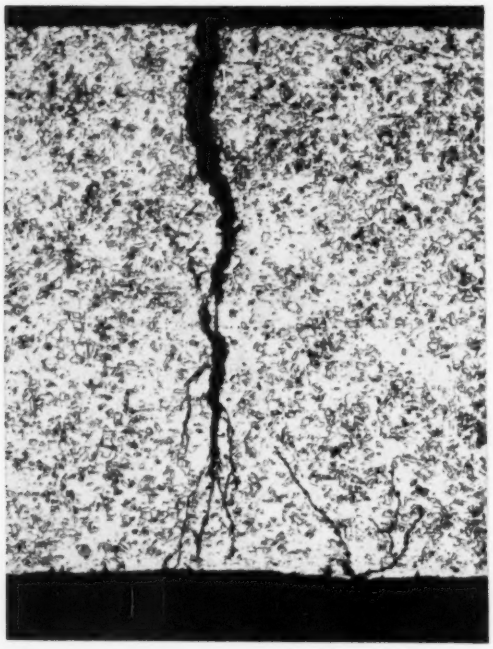
Although KOH solutions result in entirely intercrystalline cracking, the mode of attack on specimens contaminated with KOH and exposed to high-pressure steam varies with the test temperature. At temperatures above the melting point (380°C) the cracking is transcrystalline and at temperatures below the melting point is mainly intercrystalline. Figures 10 and 11 show typical areas found with specimens tested above and below the melting point of KOH, and a number of results obtained with KOH at various temperatures and pressures is given in Table VII. These results show that up to 400°C the more the steam is superheated the slower the rate of attack (this was shown for chloride in the previous paper) and that the attack is more rapid if the coating is molten.

The work with inhibitors is described later but the effects of sodium silicate on structural characteristics of the cracking is of interest at this point. Its addition to the caustic soda contaminating a sample exposed to steam caused the cracking to become inter- instead of transcrystalline, while its addition to potassium hydroxide sometimes caused a change in the type of cracking, from inter- to transcrystalline, presumably by interaction of the salts. This was confirmed by intentional addition of potassium silicate to NaOH which resulted in transcrystalline attack and to KOH which gave rise to intercrystalline attack.

TABLE VI Tests in high-pressure steam on specimens contaminated with NaOH

Type of test	Applied stress, tons/in²	Specimen temp., °C	Pressure, tons/in²	Time to failure	Remarks
	13·0	275	1100	1 cycle UB‡	
Dew-point	13·0	285	1600	1 cycle	
	13·0	295	1150	1 cycle	
	13·0	330	600	1 cycle	Failed during steam build-up
	13·0	330	1500	13 h	
	13·0	330	1500	110 h	
Superheat	13·0	330	1500	275 h UB‡	
	13·0	350	1350	1 cycle	Failed during steam build-up
	13·0	350	1000	13 h	
	5·0	330	1500	164 h	
	5·0	330	1500	283 h	Specimen softened after machining
	2·0	330	1500	617 h	Specimen softened after machining

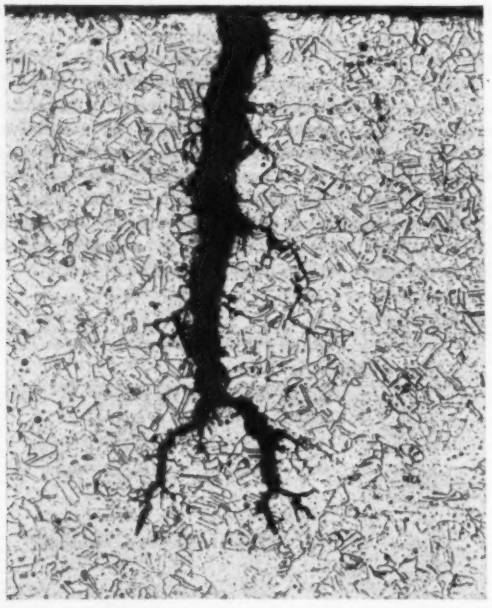
‡UB = Unbroken, no loss of pressure



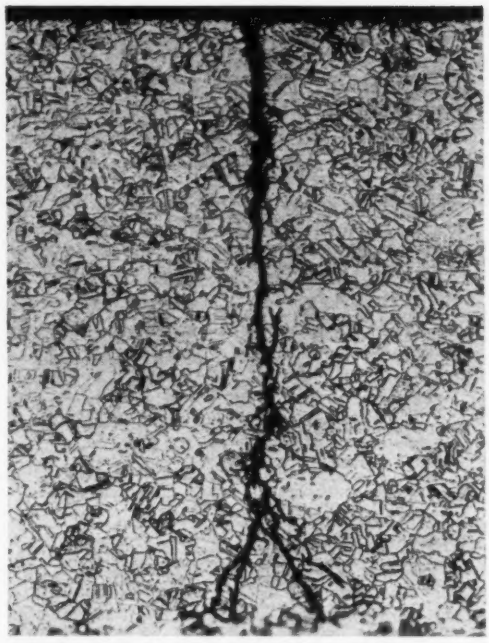
9 *Transcrystalline cracking with* NaOH *in steam* ×100

CIRCULATING WATER APPARATUS

This apparatus simulates the crevice conditions frequently met in practice, in which concentration can occur, and was described in detail in the previous paper.[2] Basically it consists of a hollow specimen with associated pipe-work and a reservoir which allow thermal circulation, the system being filled with a very dilute solution. By boiling the solution in the hollow specimen, it is caused to concentrate.



10 *Intercrystalline cracking with* KOH *below its melting point in steam* ×200



11 *Transcrystalline cracking with* KOH *heated above its melting point in steam* ×200

The behaviour of dilute chloride solutions (100 ppm) was described in the previous paper and the tests described here were conducted with 100-ppm solutions of NaOH giving a pH of around 10·8 at RT. These have shown that higher superheat values are required to cause concentration of caustic, and that even when concentration does occur, attack is less rapid than with chloride. Working at 1500 lb/in², a specimen temperature of 330°C (15°C superheat) causes concentration of chloride and failure under a 10 tons/in² stress in 24 h. With NaOH, at 330°C, no failure occurred in 350 h, and even at 360°C (45°C superheat) failure took 42 h and the single crack was found to be intercrystalline. This seems to be consistent with the work with solutions where it was found that a higher concentration of caustic soda than NaCl was required for a given rate of attack and that NaOH solutions caused intercrystalline attack.

INHIBITORS

It was shown previously[2] that prevention of cracking over relatively short periods was possible under steam conditions by addition of sodium phosphate or sodium nitrite to sodium chloride contaminating a

TABLE VII Effect of temperature and pressure in tests with KOH (MP 380°C) at 13 tons/in²

Specimen temp, °C	Steam pressure, lb/in²	Superheat, °C	Life, h	Remarks
250	400		1 cycle	Failed during steam build-up
330	1500	15	163	
330	0	330	676 UB‡	Slight cracking
400	1500	85	28	
400	0	400	501 UB	Slight cracking

‡ UB = Unbroken

TABLE VIII Effects of inhibitors with sodium chloride and sodium hydroxide under various test conditions

Type of test	Contamination	Applied stress, tons/in²	Spec. temp., °C	Steam pressure, lb/in²	Life obtained	Remarks
Dew-point steam	NaCl	13	300	1 500	1 cycle	Complete fracture
	70–30NaCl–K_2HPO_4	13	300	1 500	1 cycle UB‡	No cracking
	5–1NaCl–K_2HPO_4	13	300	1 500	1 cycle	Complete fracture
	50–50NaCl–Na_2HPO_4	13	300	1 500	1 cycle UB‡	No cracking
	50–50NaCl–Na_2SO_4	13	300	1 500	1 cycle	Complete fracture
Superheat steam	NaCl	13	332	1 500	96 h	Complete fracture
	50–50NaCl–Na_2HPO_4	13	330	1 500	3506 h UB	1 crack extending ¾ wall thickness
	50–50NaCl–$NaNO_2$	13	330	1 500	1510 h UB	,,
	50–50NaCl–$NaNO_2$	13	330	1 500	2135 h UB	No cracking
	1–2NaOH–Na_2HPO_4	13	330	1 500	460 h UB	Slight cracking
	2–1NaOH–Na_2HPO_4	13	330	1 000	5 h	Failed during steam build-up
	50–50NaOH–$NaNO_2$	13	330	1 500	313 h	Complete fracture
Solution	3%NaCl	10	250	...	1·6 h	Complete fracture
	0·1%NaCl	10	250	...	43 h	Complete fracture
	0·1%NaCl–0·1%Na_2HPO_4	10	250	...	360 h UB	Very slight cracking
	3%NaCl–1½%Na_2HPO_4	10	250	...	0·6 h	Single crack
	3%NaCl–3%$NaNO_2$	10	250	...	671 h UB	No cracking
	3%NaCl–1½%$NaNO_2$	10	250	...	36 h UB	No cracking
Circulating water	100 ppm NaCl	10	330	1 500	24 h	Complete fracture
	100 ppm NaCl–100 ppm Na_2HPO_4	10	330	1 500	360 h	
	100 ppm NaCl–100 ppm $NaNO_2$	10	330	1 500	66 h 100 h	
	100 ppm NaCl–100 ppm Na_2SO_4	10	330	1 500	176 h 350 h	
	100 ppm NaCl–100 ppm K_2SO_4	10	330	1 500	96 h 330 h	

‡ UB = Unbroken

specimen exposed to dew-point or superheat conditions.

Further tests over longer periods in the steam apparatus and also with high-temperature solutions and the circulating-water apparatus, have shown that with suitable additions a very large measure of protection is possible. Although cracking has not been completely prevented in some cases, an increase in life of up to several hundred times has been achieved. Table VIII gives a selection of the results obtained. Behaviour with NaOH was less promising and although some improvement was effected, in general the quantity of inhibitor required was greater than with NaCl as will be seen from the results which are also given in Table VIII.

Sodium phosphate or sodium nitrite added in equal quantity to the NaCl present has, in most cases, considerably increased life. Cracking which did occur was generally localized.

Potassium phosphate also was successful in the dew-point steam test in providing protection even in a ratio of more than 2:1 chloride/phosphate. For comparison the lives obtained with plain chloride contamination in the various tests are also given in Table VIII.

Sodium sulphate which was ineffective in the steam tests gave protection equal to phosphate in the circulating-water test when present in equal quantity to the chloride (100 ppm). Hall, in his extensive work on boiler-water treatment,[5] showed that potassium salts required much higher superheat values to cause precipitation, and the effect of potassium sulphate was checked under similar conditions with both KCl and NaCl. These tests too were successful, an increase of several times the life of a plain chloride test being achieved.

DISCUSSION

The results reported have clearly demonstrated a number of important points which are reviewed below.

Unexpectedly low concentration of chloride can produce rapid attack if other conditions are right; high stress and elevated temperatures are necessary for the most rapid rates of attack and reduction of one or both of these variables causes a marked decrease in the rate of attack. Efficient de-aeration can prevent attack and from the practical aspect this is probably often the easiest and most convenient preventive measure, since temperature and concentration may be predetermined by a particular process and effective stress relieving is very difficult. The rapid rates of attack experienced with all solutions from almost saturation level down to 0·1%NaCl are consistent with the results of dew-point experiments with chloride contamination reported in the previous paper[2] in which complete fracture of specimens stressed to 13 tons/in² occurred within a few minutes of the onset of condensation.

The failures at atmospheric boiling point with 6–20% NaCl solutions are interesting and indicate that whilst the stress corrosion of this type of alloy due to NaCl (as distinct from $MgCl_2$ solutions) is a possibility under these conditions it requires the joint action of high stress and concentrated solution.

The close interdependence of temperature, stress, and concentration, together with the effect of absence of oxygen, noted by several workers[2, 6, 7] and confirmed again in the present work, probably determines the useful life of existing plant, since it is likely that only rarely will the optimum conditions for very rapid attack occur. That these conditions can arise, however, is shown by the number of service failures which have occurred.[8]

The behaviour of oversaturated solutions differs from that of solutions less than saturation value. Cracking occurs much more slowly and takes a different form; the cracks lack the usual fine-branched appearance of typical stress-corrosion cracks, as found with all the more dilute solutions, being broader and

stubbier and filled with corrosion product. This resembles the type of attack found with 'superheat' steam tests and is probably because although an electrolyte is present it is approaching dryness and is consequently less efficient.

Because of the higher solubilities of sodium and potassium hydroxides, together with their comparatively low melting points, there is no upper limit to the concentration of caustic which will produce rapid attack under suitable conditions. The minimum concentration is, however, higher than with chloride and, in general, the rate of attack is somewhat slower. Both sodium and potassium hydroxide solutions up to 50% cause intercrystalline cracking as does KOH below its melting point in high-pressure steam. It was thought that at higher concentrations more nearly approaching the solid (as in the steam tests) particularly with NaOH there might be a change in the mode of attack from intercrystalline to transcrystalline cracking. Accordingly, two tests, one with 75%KOH, the other with 75%NaOH, at 10 tons/in^2 and 300°C were carried out. The KOH solution still gave entirely intercrystalline cracking but the NaOH solution produced very much mixed inter- and transcrystalline cracking which seems to fit in well with the entirely transcrystalline attack found with solid NaOH contamination of specimens exposed to high-pressure steam. KOH above its melting point and NaOH both above and below its melting point result in transcrystalline cracking in steam.

The intercrystalline attack by mixed NaOH–$Na_2Si_4O_9$ in steam and by NaOH and KOH solutions might be accounted for by carbon, or sub-microscopic carbide, concentration at or near the grain boundary which, under certain conditions, could introduce corroding paths. Diffusion by long soaking at high temperature followed by a rapid quenching should remove the tendency for intercrystalline attack and result in transcrystalline attack under all conditions.

However, samples treated for 6 h at 1050°C and quenched in iced brine at −10°C suffered intercrystalline cracking in sodium and potassium hydroxide solutions and with KOH or mixed NaOH–$Na_2Si_4O_9$ in the steam phase, but specimens made from a low carbon (0·029%) 18–10 steel in the normal air-cooled condition exhibited transcrystalline cracking in the above tests. Thus it would seem that with a higher carbon content a sufficiently rapid quench cannot be easily attained in practice to hold the carbon uniformly in solution. This effect of carbon was first noticed with a number of experimental alloys of 20%Cr–20%Ni with low carbon which had been made for another purpose but which were also tested as above and in which the cracking was wholly transcrystalline.

These observations seem to confirm that the presence of a carbide (probably chromium carbide) or the associated chromium-depleted grain edge provides a preferential path for attack under certain conditions.

It seems rather surprising that no reports of intercrystalline service failures due to caustic contamination have been made in view of the intercrystalline cracking found in tests in the circulating-water apparatus with water containing 100 ppm NaOH (pH roughly 10·8), since this would appear to simulate conditions likely to be met in crevices in heat exchangers, and the like, where concentration can occur. A factor which may explain the absence of such failures is the effect described by Hall[8] whereby presence of other salts in solution can prevent caustic build-up. A further and probably more likely possibility is that such failures that have occurred have been wrongly attributed to ordinary intercrystalline corrosion.

The results obtained with inhibitors, particularly sodium phosphate and sodium nitrite, under the extremely severe test conditions, suggest that addition of one of these salts may in some cases be a practical means of preventing stress corrosion. Where trouble arises as a result of concentration of a very dilute solution, as in the case of cooling water containing at most only a few hundred ppm of chloride, addition of an equivalent amount of an inhibitor may completely prevent or greatly reduce the attack. Where larger concentrations of chloride are involved, however, this may not be either a practical or economical method of alleviation and other means, such as stress relieving (if this can be efficiently carried out), removal of sites of possible further concentration, and reduction of operating temperature, would have to be adopted.

CONCLUSIONS

The conclusions to be drawn from the work are as follows:

(1) Stress corrosion of 18–9 Nb steel is possible in chloride solutions ranging from 50% to 100 ppm in the presence of oxygen at temperatures ranging upwards from 150°C (though this figure can be lower with the higher concentrations) and with applied tensile stress down to 2 tons/in^2 or lower. Rate of attack varies with concentration, stress, and temperature, increasing with all three. The manner in which the cracking occurs varies with the concentration of solution. Below saturation the cracking is typical of the transcrystalline type usually found with this material. Oversaturated solutions, however, result in broad stubby cracks usually filled with corrosion product.

(2) Sodium and potassium hydroxide solutions from 50–1% result in stress-corrosion cracking which is generally slower than with chloride and which is intercrystalline in nature, while 75%NaOH produces mixed intercrystalline and transcrystalline cracking but 75%KOH causes entirely intercrystalline attack. Effects of stress, concentration, and temperature are similar to those found with chloride.

(3) Both inter- and transcrystalline cracking are possible with sodium and potassium hydroxide in high-pressure steam under certain conditions. Potassium hydroxide gives rise to intercrystalline cracking below its melting point and transcrystalline cracking above, while sodium hydroxide normally causes transcrystalline attack, both above and below the melting point, which is changed to intercrystalline if sodium silicate is added.

(4) The intercrystalline nature of the cracking under certain conditions is a function of the carbon content of the steel. Alloys containing only about 0·03% of carbon exhibit transcrystalline cracking under similar conditions to those giving intercrystalline failure at 0·07–0·11% carbon levels. This suggests that the presence of a sub-microscopic grain-boundary carbide phase or its associated effects is responsible for the intercrystalline attack.

(5) Certain salts when added to chloride or caustic can delay or completely prevent stress-corrosion failure. Of the substances tried, Na_2HPO_4 was found to give greatest protection under all the test conditions.

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REFERENCES

1. German Boiler Operators' Conference: *Steam Eng.*, 1958, **28**, 22–23.
2. C. Edeleanu and P. P. Snowden: *JISI*, 1957, **186**, 406–422.
3. J. Wanklyn and D. Jones: *Chem. Ind.*, 1958, 888–889.
4. P. P. Snowden: *ibid.*, 1692.
5. R. E. Hall: *Trans. ASME*, 1944, **66**, 457–488.
6. W. Lee Williams: *Corrosion*, 1957, **13**, August, 67–73.
7. J. J. Harwood: 'Symposium on stress-corrosion cracking', 1–20; 1956, London, John Wiley and Sons.
8. 'Survey of stress-corrosion cracking in service', ASTM–NACE.

The accuracy of point counting in metallographic investigations

T. Gladman and J. H. Woodhead

SYNOPSIS

In estimating the proportions of any constituent in a microstructure it is desirable that the accuracy of the estimate should be known. When the proportion is determined by point counting it is suggested that the results should conform to the well known binomial distribution. If this is the case, the accuracy of any estimate may be calculated directly from the observed proportion and the number of points counted. The limits of applicability of the distribution are discussed and experimental evidence is presented which confirms that valid deductions from the properties of the distribution may be made for a wide range of microstructures. Tables are given so that the need for any calculation may be avoided. 1629

METHODS OF ESTIMATING the properties of the various constituents in a microstructure have become widely used in recent years. The most commonly employed method is that known as point counting. In this method, a regular grid is superimposed on the microstructure and the number of intersections of the grid lines which lie in each constituent is determined. The proportion by volume of each constituent of the structure is then the same as the ratio of the number of intersections lying in that constituent to the total number of intersections.

The labour involved in carrying out such a determination can be eased considerably by the use of semi-automatic devices. That used by the authors (the Swift automatic point counter) consists of a counter unit and a special microscope stage. The counter unit has a number of keys, depression of which causes the addition of one unit to a counter associated with that key, and at the same time causes the microscope stage to advance by a constant interval. In use, a key is assigned to each constituent present in the microstructure and that one is depressed which corresponds to the particular constituent lying under the intersection of the cross-wires in the microscope eyepiece. The counter unit records the total number of points observed as well as the numbers corresponding to each constituent. Provision is also made for advancing the stage without operating the counters, and for independent operation of the various counter dials so that any mistakes may be corrected. When the limit of travel of the stage is reached, the specimen is moved a definite distance at right angles to the previous direction of travel and the whole procedure started again. Thus the result of these operations is the same as would be achieved by counting the intersections of a superimposed rectangular grid.

However, even when using such a device, the method is laborious and conducive to eyestrain. The authors therefore decided that it would be useful to determine the relationship between the accuracy with which the proportion of a constituent could be estimated and the number of points counted. This general problem does not seem to have been studied previously although Howard and Cohen* investigated the accuracy of the point-counting technique in comparing it with the somewhat similar method of lineal analysis.

THEORETICAL TREATMENT

Consider a structure having only two constituents which exist in proportions p and $1-p$. Then, provided that the constituents are arranged at random, the probabilities that any observed point will lie in one or other of the two constituents are also p and $1-p$ respectively.

In point counting a certain number n of points is observed and the proportion z of these which lie in the constituent being investigated is determined. An estimate of the true proportion p of that constituent is then given by z. However, it is clear that, in general, z

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* R. T. Howard and M. Cohen: *Trans. AIME*, 1947, **172**, 413–426.

and p will not be equal and it is desirable to know the extent by which z may be expected to deviate from p.

If a number of sets of n points are counted, the values of z obtained from each set will be scattered about the true value p and from these values it is possible to estimate the constants (mean and standard deviation) of the distribution of a hypothetical infinite population of z's derived from sets of n points. The standard deviation of this distribution is the quantity from which the accuracy of z may be assessed.

It does not seem to have been noted previously that the properties of this distribution may be determined mathematically without recourse to experiment. The proportion z of n points lying within a randomly distributed constituent whose probability of occurrence at any one point is p, is a random variable whose distribution has a simple mathematical form and is known as the binomial distribution. The properties of this distribution are well known and can be found in any good textbook on statistical methods. It is sufficient to note that when the variable is measured as a proportion, the mean μ and standard deviation σ of the distribution are given by:

$$\mu = p$$
$$\sigma = \sqrt{[p(1-p)/n]}$$

The standard deviation σ of the distribution can be readily computed for any values of p and n.

From the formula for standard deviation it follows that the number of points to be counted for any desired value of σ is:

$$n = [p(1-p)]/\sigma^2$$

The same principles should be true for a microstructure containing more than two constituents. In this case the proportion of the ith constituent may be written as p_i and the proportion z_i of n points lying in this constituent will be a random variable conforming to the multinomial distribution. Again:

$$\mu_i = p_i$$
$$\sigma = \sqrt{[p_i(1-p_i)/n]}$$

Thus we see that exactly the same formula gives the value of the standard deviation no matter what the number of constituents may be.

It must be admitted that the application of these principles to point counting is an approximation, as the strict requirements for the validity of the binomial distribution may not be met. However, the authors contend that, in general, the approximation will be a good one and experimental evidence is presented to support this contention. The essential requirement for the binomial distribution is that each point of the grid must have a chance p of being in the constituent considered, independently of the other points. Also the binomial implies a finite probability p^n of all n points being in the constituent and $(1-p)^n$ of no points being in the constituent.

It is obvious that, if the particles are large compared with the grid size and are regular in shape, then several adjacent points will fall in the constituent and the probability of no points lying in the constituent is zero instead of $(1-p)^n$. Hence the approximation requires that the structure be finely divided relative to the grid spacing.

Also, if the constituent is considered to be divided into k particles all much smaller than a grid spacing, then if one point falls in one of the k particles, there are only $k-1$ particles for another point to fall in and its chances are reduced. This effect will be small if k is much bigger than the number of points n.

A regular pattern in the distribution of particles could also lead to difficulties. In the extreme case it is possible to imagine a regular arrangement of particles such that every grid point lies either in or out of the constituent depending on the relative positions of the grid and the particles. Fortunately such cases are most unlikely to occur.

In cases where the binomial does not apply, the accuracy is likely to be greater than that predicted so that in any case the use of the approximation will not exaggerate the accuracy.

EXPERIMENTAL WORK ON POINT COUNTING

It is clearly desirable to test the theoretical conclusions before accepting them as a sound basis from which to assess the number of points required for a stated accuracy. To do this it is necessary to estimate standard deviations associated with a variety of numbers of points and preferably a variety of structures.

Five samples were used and these represented the most common types of structure encountered. These were:

(i) a polygonal structure of ferrite and pearlite in a normalized 0·29%C steel
(ii) an acicular structure of 50% untempered and 50% tempered martensite in a 0·3%C–Ni–Cr steel
(iii) an acicular structure of 70% untempered and 30% tempered martensite in a 0·3%C–Ni–Cr–Mo steel
(iv) an acicular structure of 90% untempered and 10% tempered martensite in a 0·3%C–Cr–Mo steel
(v) a globular structure of carbides in ferrite in a 0·89%C steel.

The proportions of pearlite, cementite, and tempered martensite were determined in the above structures.

To estimate the standard deviation of the proportion z, determined from a count of n points, the following procedure was adopted.

A number k of groups, each containing n points were counted, and a value of z determined for each group. The best estimate of the proportion p is given by the mean value of z, i.e. $\bar{z}$, where

$$\bar{z} = (\Sigma z)/k$$

The standard deviation of the distribution of z as estimated from n points is:

$$s_n = \sqrt{[\Sigma(z-\bar{z})^2/(k-1)]}$$

The standard error of $\bar{z}$ is:

$$\mathrm{SE}(\bar{z}) = s_n/\sqrt{k} = \sqrt{\{\Sigma(z-\bar{z})^2/[k(k-1)]\}}$$

and this is clearly to be equated with the standard deviation σ of the distribution of z as estimated from nk or N points.

Thus for each count of N points, two values of the standard deviation are determined, associated with N and n points respectively.

This procedure was repeated on each specimen for a number of values of n. In the samples containing 50% of tempered martensite, a number of estimations of s_n

were made for the same value of n. This was done to give some indication of the distribution of s_n about σ, for it must be realized that s_n has a sampling distribution and is only an estimate of σ.

For each sample, the proportion of the constituent investigated was estimated as the grand mean of all results on that sample. This value was then used as p to calculate σ for the various values of n and N from the formula:

$$\sigma = \sqrt{[p(1-p)/n]}$$

TABLE I Results on pearlitic steel ($p = 0{\cdot}556$)

Number in sample, n	Number of samples, k	Total number of points, $N=nk$	Mean proportion, $\bar{z}$	s_n	σ_n	SE($\bar{z}$) $=s_N$	σ_N
25	20	500	0·572	0·087	0·099	0·0195	0·0222
25	20	500	0·526	0·098	0·099	0·0220	0·0222
25	40*	1000	0·549	0·095	0·099	0·0150	0·0157
50	15	750	0·555	0·114	0·070	0·0293	0·0181
120	5	600	0·573	0·052	0·045	0·0233	0·0203
10	25	250	0·548	0·181	0·157	0·0361	0·0314

* These 40 samples are a combination of the first two sets of 20.

TABLE II Results on martensitic steel ($p = 0{\cdot}494$)

Number in sample, n	Number of samples, k	Total number of points, $N=nk$	Mean proportion, $\bar{z}$	s_n	σ_n	SE($\bar{z}$) $=s_N$	σ_N
50	20	1000	0·494	0·047	0·071	0·0105	0·0158
52	20	1040	0·491	0·070	0·069	0·0157	0·0155
48	20	960	0·482	0·049	0·072	0·0110	0·0161
50	20	1000	0·535	0·055	0·071	0·0123	0·0158
50	20	1000	0·486	0·072	0·071	0·0161	0·0158
50	20	1000	0·476	0·094	0·071	0·0210	0·0158

TABLE III Results on martensitic steel ($p = 0{\cdot}328$)

Number in sample, n	Number of samples, k	Total number of points, $N=nk$	Mean proportion, $\bar{z}$	s_n	σ_n	SE($\bar{z}$) $=s_N$	σ_N
10	30	300	0·347	0·150	0·148	0·0274	0·0271
100	5	500	0·316	0·026	0·047	0·0166	0·0210

TABLE IV Results on martensitic steel ($p = 0{\cdot}103$)

Number in sample, n	Number of samples, k	Total number of points, $N=nk$	Mean proportion, $\bar{z}$	s_n	σ_n	SE($\bar{z}$) $=s_N$	σ_N
10	16	160	0·094	0·104	0·096	0·0260	0·0240
20	11	220	0·109	0·075	0·068	0·0226	0·0205

TABLE V Results on spheroidized steel ($p = 0{\cdot}282$)

Number in sample, n	Number of samples, k	Total number of points, $N=nk$	Mean proportion, $\bar{z}$	s_n	σ_n	SE($\bar{z}$) $=s_N$	σ_N
25	20	500	0·297	0·068	0·090	0·0153	0·0201
60	10	600	0·262	0·042	0·058	0·0134	0·0184
15	20	300	0·297	0·107	0·116	0·0239	0·0260

TABLE VI Results on random numbers ($p = 0{\cdot}500$)

Number in sample, n	Number of samples, k	Total number of points, $N=nk$	Mean proportion, $\bar{z}$	s_n	σ_n	SE($\bar{z}$) $=s_N$	σ_N
25	22	550	0·496	0·098	0·100	0·0210	0·0213
25	22	550	0·483	0·069	0·100	0·0147	0·0213
25	22	550	0·456	0·097	0·100	0·0207	0·0213
50	11	550	0·484	0·063	0·071	0·0190	0·0213
50	11	550	0·466	0·081	0·071	0·0244	0·0213
10	55	550	0·500	0·183	0·158	0·0246	0·0213
10	55	550	0·466	0·170	0·158	0·0229	0·0213

RESULTS

The experimental results are shown in Tables I–V, together with the calculated values of σ.

The experimental values of s conform reasonably well to the theoretical values of σ although there is appreciable scatter. Whether or not this scatter is of a magnitude to be expected can be investigated theoretically but it seemed wise to test other data known to conform to the binomial distribution to obtain results which can be compared with those obtained by point counting. This was done by determining the proportion of odd numbers, z, in k sets of n two-figure random numbers. In this case the value of p is known exactly since there are equal numbers of odd and even numbers and $p = 0{\cdot}500$. The results are set out in Table VI.

DISCUSSION OF RESULTS

Clearly, the results of the random-numbers experiment should conform to a binomial distribution with $p = 0{\cdot}5$. Table VI indicates that this is the case but again there is the expected scatter in s. The scatter in this case is wholly comparable with that found in the point-counting experiments.

The agreement of theory and experiment is also shown by Fig.1, in which all the experimental values of s are plotted against their theoretical equivalents σ. A straight line of unit slope and zero intercept is a satisfactory representation of the results; a line fitted by the method of least squares agrees with such a representation to well within the limits of experimental error. This shows that, on the average, experimentally determined values of s tend to the theoretical values of σ and that it is reasonable to use the calculated σ to specify the accuracy of a point-counting experiment.

It may be thought that the scatter of the values of s is rather large but it has been shown that comparable scatter is obtained on testing data known to conform to the binomial distribution. This question of scatter may, however, be treated more rigorously by making use of the concept of confidence intervals. It has been stated earlier that s is an estimate of σ and will necessarily show some variability. For any given experimentally determined value of s it is possible to calculate limits within which the true value σ may be said to lie with any required probability; the higher the specified probability, the further apart these limits will be. Such limits are known as confidence limits and the interval between them as a confidence interval. The probability used in specifying confidence intervals may be chosen at will and one has the choice of making rather general statements with a high probability of being correct or more specific statements with a lower

TABLE VII Standard deviation as a function of n and p

n	p 0·02	0·04	0·06	0·08	0·10	0·15	0·20	0·25	0·30	0·40	0·50
200	0·010	0·014	0·017	0·019	0·021	0·025	0·028	0·031	0·032	0·035	0·035
400	0·007	0·010	0·012	0·014	0·015	0·018	0·020	0·022	0·023	0·024	0·025
600	0·006	0·008	0·010	0·011	0·012	0·015	0·016	0·018	0·019	0·020	0·020
800	0·005	0·007	0·008	0·010	0·011	0·013	0·014	0·015	0·016	0·017	0·018
1000	0·004	0·006	0·007	0·009	0·009	0·011	0·013	0·014	0·014	0·015	0·016
1500	0·004	0·005	0·006	0·007	0·008	0·009	0·010	0·011	0·012	0·013	0·013
2000	0·003	0·004	0·005	0·006	0·007	0·008	0·009	0·010	0·010	0·011	0·011
3000	0·003	0·004	0·004	0·005	0·005	0·007	0·007	0·008	0·008	0·009	0·009
4000	0·002	0·003	0·004	0·005	0·006	0·006	0·006	0·007	0·007	0·008	0·008
5000	0·002	0·003	0·003	0·004	0·004	0·005	0·006	0·006	0·006	0·007	0·007

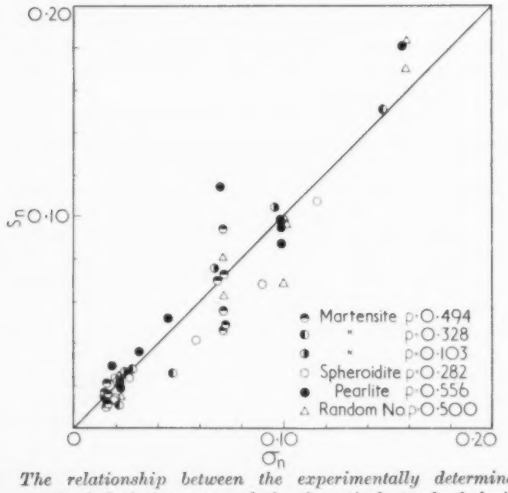
probability of being correct. The most generally used confidence intervals are those for which there is a probability of either 0·95 or 0·99 that the true value lies within the interval. These intervals are usually termed 95% and 99% confidence intervals respectively. If 95% confidence intervals for σ are calculated from the experimentally determined values of s, we find that in all but two cases the σ's obtained from the binomial distribution lie within the intervals. All values lie within the 99% confidence intervals.

Consequently we may regard it as proved that standard deviations calculated from the binomial approximation provide a satisfactory description of the accuracy obtained in point counting for the specimens investigated. As these specimens cover a variety of structures and values of p ranging from 0·1 to 0·5, it seems reasonable to suppose that the application of this approximation is valid generally, subject to the restrictions mentioned earlier, i.e. that the constituents shall be distributed at random, that the number of particles shall be large compared with the number of grid points and that the structure shall be finely divided relative to the grid spacing. If these restrictions are not met it is likely that the binomial approximation will underestimate the accuracy of a determination.

APPLICATION OF THE BINOMIAL APPROXIMATION

The standard deviation of the binomial distribution is given by

$$\sigma=\sqrt{[p(1-p)/n]}$$



1 *The relationship between the experimentally determined standard deviations, s, and the theoretical standard deviations, σ, for all structures*

For any given value of p, the proportion of a particular constituent of the microstructure, the standard deviation, σ, is readily calculable from the number of points counted, n. The results of such calculations are collected in Table VII which gives the values of σ for selected values of p and n. The tabular intervals are sufficiently close for interpolation to be easy. The values of σ are given only to the third decimal place as it is considered that this is sufficient for practical purposes. This table makes it easy to assess the accuracy of any point-counting result using the observed proportion z as an estimate of p and taking into account the total number of points counted.

It is frequently desirable to know how many points should be counted in order to obtain a desired accuracy. In this case the foregoing formula may be rearranged giving

$$n=p(1-p)/\sigma^2$$

and the number n computed accordingly. Table VIII presents the results of such calculations for a range of values of σ and p. For most practical work, the desired n may be estimated sufficiently well from this table without calculation.

It may be objected that there is no estimate of p until the count has been made. However, a rough visual estimate will serve to give some idea of the required number of points and this can be adjusted by calculating the observed proportion based on the first 100 or 200 points.

The relationship of σ to the accuracy with which we determine the proportion p should now be considered. This is best specified in terms of a confidence interval, i.e. it is required to know between what limits the unknown proportion p lies for observed values of z and σ. These limits will, of course, depend on the probability used to specify the confidence interval. The strict determination of confidence limits for a binomial distribution is not easy unless one has suitable tables available. However, when n is large (greater than, say, 200) as it always will be in point counting,

TABLE VIII Number of points as a function of p and σ

p	σ 0·001	0·0025	0·005	0·0075	0·010	0·025
0·02	19600	3163	784	348	196	
0·04		6144	1536	683	384	
0·06		9024	2256	1003	564	
0·08			2944	1308	736	
0·10			3600	1600	900	144
0·15			5100	2267	1275	204
0·20			6400	2844	1600	256
0·25				3333	1875	300
0·30				3733	2100	336
0·40					2400	384
0·50					2500	400

the binomial distribution may be approximated sufficiently well by a normal or Gaussian distribution with the same mean and standard deviation. This approximation is satisfactory for values of p ranging from 0·1 to 0·9 when n is greater than 200 and if we increase n to 400 or more then the range of values of p may be extended to 0·02 and to 0·98.

On the basis of this approximation we can say that the true value of p has a 0·95 probability of being between $z-1{\cdot}96\sigma$ and $z+1{\cdot}96\sigma$ (95% confidence limits). The corresponding 99% confidence limits are $z\pm2{\cdot}6\sigma$.

If a high degree of accuracy is sought for any one sample, the number of points to be counted will be very large, e.g. suppose we have a sample for which p is about 0·5 and we decide that we need a standard deviation of 0·005 so that the 95% confidence limits for p are $z\pm0{\cdot}01$ (very nearly), then the required number of points n is 10000.

Projects involving point counting, however, usually involve a number of samples which may be used to determine the relationship between the amount of a phase present and some other variable. Where a number of samples are used in this way, then some reduction in the degree of confidence for a specific sample may be tolerated without endangering the significance or accuracy of the relationship so determined.

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The spectrographic determination of residual elements in steel by the excitation index technique

K. M. Bills

SYNOPSIS

The formulation of a standard method for the determination of minor elements in low-alloy steel is made particularly difficult by the great variety of light sources used to excite the sample. Individual laboratories have been reluctant to abandon satisfactory non-standard source units solely to achieve a greater uniformity of method. A collaborative investigation by a Study Group of the BISRA Spectrographic Analysis Sub-Committee is described which has established a common basis whereby a variety of intermittent ac and dc arc source units may be used for the determination of residual elements in mild and low-alloy steels. The excitations are specified in spectroscopic rather than electrical terms by means of the intensity ratio of a non-homologous line pair of the major element. This 'excitation index' method has been applied to the determination of Co, Ni, Ti, Zr, Cu, Sn, Mo, Cr, Nb, V, *and* Al *at contents down to 0·01%. A mean coefficient of variation of ±4·2% has been achieved.*

1763

INTRODUCTION

THE MAJOR TASK of the BISRA Spectrographic Analysis Sub-Committee is to study spectroscopic problems confronting the iron and steel industry and, where possible, to evolve recommended analytical techniques by means of co-operative research. One such method for the determination of alloying elements in low-alloy steel has been adopted as a British Standard technique. The existence of a light source common to all participants, i.e. the simple Hilger condensed spark, enabled the field of enquiry to be appreciably reduced. There is general agreement not only among spectrographers in the UK but also on the continent and in the USA that for the determination of contents exceeding, say, 0·05%, a spark source is required producing spectra predominantly of singly ionized atoms of the sample. No such unanimity is found to exist when the many methods proposed for the determination of residual elements are considered. High-voltage ac arcs, intermittent ac and dc arcs, and continuous dc arcs have all been proposed as light sources to deal with contents too low to be determined by the high-voltage spark.

Accordingly, the early efforts of the Study Group were devoted to a study of a specific light source for this purpose and its first report[1] described the determination of a limited number of residual elements using intermittent ac arc excitation. Considerable difficulties were encountered, however, in maintaining a concerted approach. It was suggested in this first

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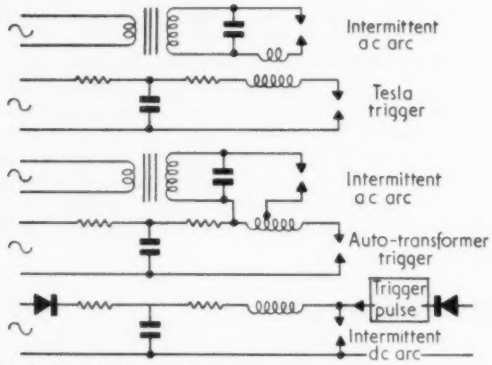
The author is with the Mond Nickel Co. Ltd.



1 *Principal features of the source units*

report that although a standard design of source unit might readily enable a standard method to be formulated, individual laboratories would not be prepared to abandon satisfactory non-standard equipment solely to achieve this. Changes in membership of the Group bringing about corresponding changes in the excitation equipment available confirmed this. All members had source units of the triggered low-voltage arc type, i.e. variants of the original Pfeilsticker circuit, but the units differed considerably in detail. Both intermittent ac and dc arcs were represented (Table I). Main features of these various light sources are shown in Fig.1. The principal difference between the two dc source units was that the trigger of the Hilger–BNF unit contributed a significant part of the total light output, whereas the contribution of laboratory D's electronic trigger was virtually negligible. It was thought that this excitation equipment represented a reasonable cross-section of such equipment at present in use in the UK. In view of the difficulties encountered in the earlier work it was decided to explore the possibility of developing a method for the determination of the commoner residual elements in mild and low-alloy steels which could be applied to all of these source units. A reproducibility of better than $\pm 10\%$ and limits of detection of 0·01% or better were aimed at.

It was necessary to ensure that all units produced similar spectra and the major task, therefore, was a study of the various factors affecting the spectrum characteristics, together with a search for practical means of defining them. Two approaches were examined:

(i) an indirect method, measuring cause rather than effect, in which the discharge current waveform, peak current, rms current, and time constant are specified

(ii) direct assessment of the degree of excitation from the actual spectra, a numerical expression of the appearance being obtained from the ratio of the intensities of two lines of the major element having widely differing excitation potentials. This ratio has commonly been described as the 'excitation index'.

Earlier work had indicated that both methods were capable of achieving a high degree of uniformity when applied to source units of similar electrical design. There was, however, considerable doubt that the first (electrical) method could be used to match units operating at different frequencies. The intermittent

TABLE I Source units used in the investigation (intermittent ac arc unit)

Laboratory	Source type	Special characteristics
A	dc	Hilger–BNF general purpose unit
B	ac	Sinclair[3] type, auto transformer-coupled trigger
C	ac	Kingsbury and McLelland[3] type, auto-transformer-coupled trigger
D	dc	Multisource type, electronic trigger
E	ac	Kingsbury and McLelland[3] type, Tesla coupled trigger

ac arc units delivered 100 discharges per second, which was twice the frequency of the dc units. Furthermore, an experiment by laboratory A showed that virtually identical spectra could be produced by the same unit using discharges of widely different discharge current waveforms. The relevant circuit parameters investigated in this particular test were, (*a*) 120 μF, 11 Ω, 60 μH, and (*b*) 170 μF, 5 Ω, 60 μH. The excitation index method was more attractive since its numerical expression was immediately intelligible to the spectrographer and no special equipment was required for its measurement. There were, however, no grounds for assuming that the intensities of lines of the residual elements themselves were simply related to the excitation index but such a hypothesis was a good basis for a collaborative investigation.

INVESTIGATION OF THE EXCITATION INDEX

Members followed the practices normal to their own laboratories. This often involved considerable variations, particularly in counter electrode shape, analytical gap spacing, and photographic processing, although the following details were common to all laboratories:

Spectrograph	Hilger, large quartz Littrow
Slit width	15 μ
Wavelength range	3500–2450 Å
Upper electrode	$\frac{1}{4}$-in. dia. graphite rod
Photographic plate	Kodak B10

Plate calibration in terms of relative intensities was used by all members.

Since the key to the whole investigation was the validity or otherwise of the excitation index/spectrum characteristic hypothesis, a deliberate effort was made to avoid an excessive amount of standardization. The Bureau of Analysed Samples Spectrographic Standards (Mild Steel Residual Series) SS 11–17 were used for calibration purposes.

A number of pairs of iron lines with widely different excitation potentials were examined to determine their suitability as a means of measuring the degree of excitation in the spectra. The line pair finally chosen was:

Wavelength	Excitation potential eV
Fe I 3175·447 A	6·3
Fe II 3177·535 A	15·54

the excitation index being defined as the logarithm of the relative intensity ratio. An increase in this value indicates a more arc-like discharge, and *vice versa*.

A preliminary survey of the practical significance of this index was carried out in which standards were exposed by the technique normally used by each laboratory. Measurements were made of the excitation indices and it was observed that these differed markedly

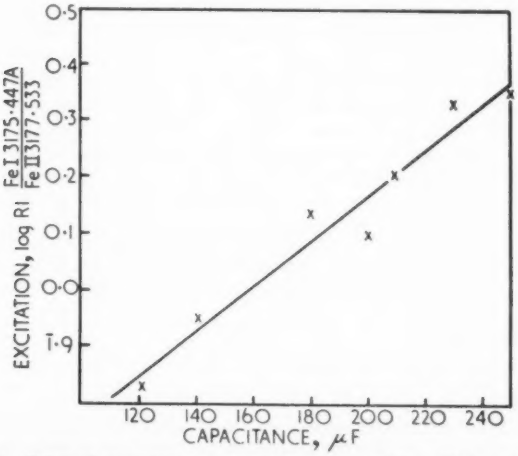
TABLE II Variation of excitation index in spectra from different steels

BAS Standard no.	Excitation index, log RI
SS 11	0·354
12	0·256
13	0·311
14	0·391
15	0·249
16	0·235
17	0·206

and consistently between the various standards. A typical set of measurements is shown in Table II. SS 11 was therefore arbitrarily chosen as the reference standard. Spectra produced by the ac units were much more dense and arc-like than those of the dc units. Measurements showed that the ac units produced excitation index values of (log) 0·4–0·6 while both dc units gave values of about $\bar{1}$·8. To some extent this behaviour was expected, since the ac units had been specifically designed to secure maximum sensitivity, while the dc units were intended to provide a whole range of discharge characteristics.

The apparent relationship between excitation index and sensitivity was encouraging and a second test was carried out in which all members tried to achieve the same excitation index at an intermediate level of 0·0 with a line density of 0·9 (12–14% transmission). The electrical parameters of the discharge circuits were altered to bring this about; time constants were increased and/or peak current decreased to make the discharge more arc-like and *vice versa*. A typical response to such adjustments is shown in Fig.2, which was recorded by laboratory A (Hilger–BNF unit) on varying the discharge capacitance.

Two intermittent dc units successfully achieved the required excitation index value but it was found to be impossible to reduce the sensitivity of the ac units sufficiently. A marked improvement in uniformity between spectra from different units was, however, obtained and this improvement had obviously been brought about by the control of excitation index and density level. A compromise value of 0·3 for the excitation index was finally found to be within the range of all source units. The excitation and exposure conditions used to achieve this are recorded in Fig.3.



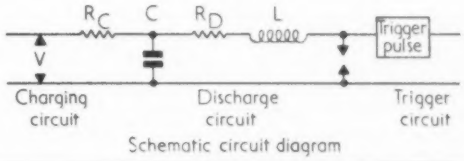
2 *Effect of capacitance on excitation index, Hilger–BNF unit*

TABLE III Variation of excitation index in samples of commercially pure iron (intermittent dc arc unit)

Material	Deflection, cm (50 cm clear plate) Fe II	Fe I	Excitation index, log RI
Powder metallurgy	16·35	15·15	0·035
Armco	14·2	12·9	0·044
Electrolytic	14·45	12·4	0·070
Millom	14·9	10·8	0·144
Swedish white iron	15·8	3·6	0·619
SS 11	12·3	6·15	0·292

The choice of analysis line pairs presented some considerable difficulties, since the spectra produced under these conditions were very complex, appearing as a composite of high voltage spark and dc arc spectra. Interference was therefore the major problem rather than lack of analysis lines of suitable intensity but a suitable list was finally approved. Tests showed the reproducibility of the excitation index to be very low (as might be expected from a line pair deliberately selected to be non-homologous) the standard deviation being $\pm$log 0·050. It was also observed that the index increased with increasing exposure time and there was considerable evidence to show that the effect was thermal in origin. A reasonable latitude in comparing excitation indices and corresponding analysis lines was obviously necessary. Obviously it was also necessary to exercise a reasonable control of the sample size so that thermal effects should not influence the results. As a general guide it appeared that samples of $\frac{3}{8}$ in. dia. or greater, were of sufficient thermal capacity about the arc crater to avoid errors of this sort.

A limited investigation was also carried out in an effort to specify the excitation index on a more absolute basis; avoiding the use of a specific composition (i.e. SS 11) and using commercially pure iron. The results of one such test using an intermittent dc arc unit (laboratory D) are shown in Table III.



Schematic circuit diagram

Lab.	Voltage	R_C, Ω	C, μF	R_D, Ω	L, mH	Upper electrode*	Analytical gap spacing, mm	Exposure time, s
A	350dc	...	230	15·0	0·06	90° pointed cone	2·0	10
B	230ac	40	80	6·7	...	90° pointed cone	3·0	25
C	230ac	30	40	7·0	0·5	80° cone 1-mm radius ball tip	2·0	50
D	350dc	...	180	5·1	1·0	90° cone 1-mm radius ball tip	2·5	40
E	200ac	60	48	...	...	90° cone 1-mm radius ball tip	2·0	120

* All laboratories used $\frac{1}{4}$-in. dia. graphite; lower electrode, sample linished flat, 60 grit.

3 *Excitation and exposure conditions, excitation index, and reproducibility tests*

TABLE IV Analysis line pairs and results of excitation index test

Analysis line pair	A	Calibration graph index value, % Laboratory A	B	C	D	E
Co I	3453·505	0·073	0·080	0·040	0·105	0·109
Fe I	3459·918					
Ni I	3414·765	0·047	0·048	0·025	0·059	0·049
Fe I	3415·534					
Ti II	3349·406	0·020	0·024	0·026	0·025	0·018
Fe	3355·229					
Cu I	3273·962	0·030	...	<0·01	0·033	0·023
Fe	3280·261					
Zr II	3273·047	0·038	0·023	0·042	0·025	0·022
Fe II	3281·300					
Sn I	3262·328	0·070	0·063	0·038	0·068	0·084
Fe I	3253·602					
Mo	3170·347	0·020	0·028	0·017	0·016	0·017
Fe II	3171·353					
Nb	3130·786	0·110	0·080	0·020	0·074	0·063
Fe II	3135·364					
V II	3093·108	0·011	0·036	0·015	0·012	0·009
Fe	3093·357					
Al I	3082·155	0·027	0·027	0·039	0·024	0·018
Fe	3080·112					
Cr II	2849·838	0·19	0·107	0·179	0·155	0·096
Fe II	2849·606					
		Excitation index, log RI				
Fe I	3175·447	0·24	0·29	0·25	0·26	0·25
Fe II	3177·535					

The purer materials gave less intense, more spark-like spectra with excitation indices fairly closely grouped around 0·050. Although it thus appeared that the excitation index tended towards a limiting value as the purity of the iron increased, nevertheless it appeared that the purity required would have to be specified. Undoubtedly this would have required a major investigation into the effect of individual elements on the excitation index which, however interesting, would not have been justified in view of the effort required. These limited findings raised some speculation on the origins of the effect of composition on the excitation conditions and a possible relationship with accuracy. A number of reasons were suggested; the most plausible being the possible presence of elements of low excitation potential lowering the average excitation and the effect of impurities on the electrical resistivity and thermal conductivity.

Therefore it was decided to retain SS 11 as the reference standard for the excitation index. To test the excitation index/spectrum sensitivity relationship SS 11–17 were exposed with the various source units adjusted to achieve an excitation index value of 0·2–0·3 at a density level of 0·9 for Fe I 3175·447, as measured on the spectrum of SS 11. The calibration curves were established and limits of detection and index values (i.e. equality points) of each line pair were measured. All laboratories achieved a limit of detection of 0·01% on all elements with the exception of tungsten, where the limit was of the order of 0·05%. The line pairs used and results obtained are recorded in Table IV. It will be seen that, within reasonable limits, similar index values were obtained for each analysis line pair. All members encountered difficulty in obtaining a good calibration curve for zirconium.

The test fully justified the use of the excitation index at a given density as a means of defining the type of spectrum. It remained to be proved whether analyses of the required reproducibility were obtained when this method of specifying excitation conditions was used.

TABLE V Reproducibility test (sample ref. no.MGS 308)

Element	Mean content, % Laboratory A	B	C	D	E	Coefficient of variation, % Laboratory A	B	C	D	E
Co	0·050	0·050	0·059	0·056	0·050	3·0	3·6	3·4	3·0	2·8
Ni	0·049	0·052	0·050	0·058	0·040	3·1	5·1	3·0	2·8	3·2
Ti	0·050	0·057	0·048	0·057	0·051	3·0	4·0	6·2	2·4	3·7
Cu	0·053	...	0·040	0·049	0·050	3·6	...	5·0	2·8	5·4
Zr	0·024	0·016	0·020	0·018	0·026	5·8	7·8	7·1	5·4	9·0
Sn	0·058	0·069	0·055	0·052	0·059	4·5	4·4	5·4	5·8	5·9
Mo	0·057	0·066	0·057	0·044	0·049	3·2	3·0	5·2	6·1	5·0
Nb	0·047	0·047	0·051	0·047	0·046	4·5	4·7	6·5	4·2	6·0
V	0·058	0·056	0·050	0·049	0·050	3·3	4·5	3·0	2·0	3·1
Al	0·052	0·057	0·050	0·052	0·053	2·1	3·5	3·0	4·0	4·7
Cr	0·051	0·053	0·052	0·056	0·054	2·7	4·2	3·8	2·3	3·8

REPRODUCIBILITY TESTS

A sample of mild steel was prepared containing about 0·05% of each of the elements of interest. The material was cast, extensively worked, and heat-treated to secure the maximum degree of homogeneity. Each member was supplied with three 1-in. lengths of $1\frac{1}{4}$-in. dia. bar with the flat surfaces linished to a standard 60 grit finish. Each piece of sample was sparked ten times (making thirty times in all) with the excitation conditions as in the preceding test. Care was taken to spark each piece consecutively to avoid excessive heating effects. The standard deviations of the logarithm of the relative intensity ratios and the coefficients of variation obtained from this value are recorded in Table V. All members succeeded in obtaining coefficients of variation of better than 10% and, in general, good agreement in the reported mean contents was achieved.

The reproducibility of the zirconium values was consistently inferior to that of other elements and it was noted that all members had previously encountered difficulty in obtaining good calibration curves for this element. Laboratory B did not report values for copper since the available plate calibration curve did not extend to sufficiently high densities. In general, however, the results were satisfactory.

DISCUSSION

The investigation proved that a good measure of standardization could be achieved with widely different source units by specifying the excitation in terms of the excitation index. A more exact correspondence of the spectra can hardly be expected with such a complex process as the excitation of metal electrodes in air. The excitation index has been shown to increase with time of sparking, presumably owing to thermal effects, but these same effects bring about a decrease in the emission of most residual elements. Unless the spectrographs have exactly the same photographic speed, even identical light sources would not produce identical spectra. The technique evolved in this investigation is not, therefore, proposed as a definitive method for the determination of residual elements in steel but as providing the basis from which the detailed procedure of such a method can be developed.

REFERENCES

1. BISRA Spectrographic Analysis Sub-Committee: *JISI*, 1955, **181**, 316–318.
2. D. A. Sinclair: *J. Opt. Soc. Amer.*, 1949, **39**, 958–966.
3. G. W. J. Kingsbury and J. A. C. McLelland: Polarographic and spectrographic analysis of high-purity zinc and zinc alloys for diecasting, 49; 1952, London, HMSO.

Discussion

Chairman at this session was Dr **A. C. G. Menzies** (Hilger and Watts Ltd).

Mr **E. van Someren** (Murex Welding Processes Ltd) said the work of Mr Bills and his Study Group was most interesting and would be of great help to all analysts dealing with low-alloy steels. One thing which would make matters easier for them would be a supply of the remarkable sample MGS 308, since it would enable each analyst to produce his own maps of all the lines likely to be used in this work. If the excitation index recommended for this method were related to MGS 308 instead of to SS 11, it would be possible to set the source unit even more readily. He would like Mr Bills' opinion of the lines proposed by Schreiber and Fry, who suggested a FeI/FeIII pair. He also thought it appropriate to refer to the work of Lacqua who had said that sources could be specified in terms of the total energy and duration of each discharge. Lacqua's work might some day be linked with analytical laboratory work, although so far it appeared not to have been thus used. He would also like to suggest the use of a hot-wire ammeter in specifying source unit conditions.

Mr **Bills** expressed his appreciation of Mr van Someren's remarks but pointed out that only a limited amount of the reproducibility test sample MGS 308 had been prepared. He agreed that the measurement of a line pair such as has been proposed by Schreiber and Fry would provide an even more sensitive indication of changes in excitation conditions, but under the conditions used a doubly-ionized iron line would not, in fact, be excited. With reference to the use of a hot-wire ammeter for measuring one of the parameters of a particular discharge he agreed that this instrument had its uses, but he would point out that in the expression for the calculation of the rms current through a spark, inductance is not involved, yet this parameter has a very profound effect on the peak current. Measurement of the rms current, however valuable, was by no means the only parameter defining the source condition.

Mr **A. Argyle** (British Cast Iron Research Association) said the author was to be congratulated for a paper given in his characteristically lucid manner. It appeared that the excitation index was affected by sample structure as well as by source unit conditions. What degree of success in setting his source unit would an operator achieve in using a particular type of iron, say Swedish white iron, the physical and chemical condition of which might vary from sample to sample?

Mr **Bills** said different types of iron were investigated as alternatives to the use of SS 11 as the reference material, the results being given in Table III of the paper. Although within any one laboratory any material could be used to line up different source units, the influence of composition had been shown to be so profound that a major investigation would have been required to determine the reasons for this. It had been found more practicable to refer to a readily available sample of known composition.

Mr **R. H. Tyas** (British Iron and Steel Research Association) observed that if it was required to calibrate for residual elements in a certain material, the obvious method was to use one of the proposed calibration standards in order to fix the excitation index. For residuals in mild or low-alloy steels, the sample to choose for a check of excitation index was one of the BCS standards and there was no doubt that the use of SS 11 would certainly achieve the desired sensitivity.

Mr **A. Harrison** (Jessop-Saville Ltd) thanked Mr Bills for providing a method of checking ac arc sources, and asked if any consideration had been given to the pure dc arc and the use of stepped sectors, or filters, to produce a choice of spectra giving suitable reproducible densities.

There were some obvious differences in the results given for reproducibility tests (for example, 0·040–0·058, 0·050–0·059) and since these were also mean results from various laboratories, total variation might be even greater. This kind of variation created a difficult problem in the release and acceptance of material. He would like to know if the use of the excitation index technique improved the results?

Mr **Bills** in reply said the terms of reference of the Study Group had been to consider methods for the determination of the stated elements with a limit of detection of 0·01% and for these purposes there was general agreement that an intermittent source would provide the best accuracy at those levels. He agreed with Mr Harrison that the dc arc was a much maligned source, and indeed a new Study Group had recently been formed by the BISRA Sub-Committee to consider the use of a dc arc for the estimation of contents below 0·01%. It might be found desirable to use suitable weakening devices before the spectrograph slit to produce stepped spectra suitable for the estimation of wide ranges of content. It was true that for certain elements the agreement between different laboratories was disappointing but he thought it was equally true that the agreement was comparable with that encountered with similar co-operative chemical investigations. It was also worth pointing out that laboratories carried out these tests 'blind' and that no results were referred back to be 'adjusted'.

In an overall sense the excitation index technique did improve the results, but it was equally true that for any given individual estimation it would probably be possible to develop a better technique.

Dr **R. Taylor** (Post Office Research Station) questioned whether Mr Bills and his study group were right to have selected the excitation index value first. For example, he noted that the limit of detection for tungsten was given as 0·050%, but if a change in source conditions would have enabled the desired sensitivity of 0·01% tungsten to be achieved should not that have been made and the excitation index for those conditions used as standard?

Mr **Bills** agreed that it would have been desirable to have met the required limit of detection for tungsten, but it was found that the two intermittent dc units were incapable of achieving this and there was general agreement that there was insufficient metallurgical interest in tungsten contents of this order to justify making major modifications to these units. The precise value of the excitation index was in effect the best compromise value which could be achieved by all participating laboratories.

Mr **R. H. Tyas** said that when the method was developed the range of concentrations to be covered was 0·01 to 0·10% for most alloying or residual elements in steel. Had the method been altered to allow tungsten to be determined at the 0·01% level, the range of analysis then covered by the method would have been 0·002 to 0·02% for most elements, and this was not desirable. A further point was that the source unit used by BISRA in this investigation was extended to its maximum as a controlled intermittent dc arc and the excitation index of 0·3 could not be taken any higher.

Dr **J. Marriott** (Imperial Smelting Corporation) said he had been interested in the use of the excitation index for specifying the source conditions in the determination of residual elements in steel. In view of the difficulty of repeating a published technique, was it considered that the specification of an excitation index for each published method would be of value in general spectrographic analysis?

Mr **Bills** replied that in view of the degree of success met with during the investigation it certainly seemed desirable that originators of methods should endeavour to quote some such excitation index for the benefit of those who might endeavour to repeat their techniques.

Mr **J. H. Oldfield** (Admiralty Materials Laboratory) said an ASTM publication on spectrochemical methods quoted excitation index values. He had tried to conform to excitation conditions given in a method using a solution technique for nonferrous alloys, but although he had obtained the quoted excitation index value, the rest of the line pairs had not conformed to those given in the method. Some caution should therefore be used in the general acceptance of the excitation index method. Nevertheless, in the account just presented the excitation index had provided a solution to the difficult problem of specifying standard excitation conditions for plain steels when the outlook for a recommended method had, in view of the various source units employed, looked very grim indeed.

Mr **M. Z. de Lippa** (Consett Iron Company) asked whether under the conditions described the spectra produced had a very heavy background, and if so whether any background correction was attempted to improve the coefficient of variation.

Mr **Bills** said the spectra obtained had an appreciable but not heavy background and as the analysis lines were considerably stronger than their adjacent background no correction had been employed. Doubtless an improvement could have been effected in this way but the Study Group had more than adequately achieved the required coefficient of variation.

Mr **J. R. Brown** (GKN Group Research Laboratory) remarked that the results Mr Bills had presented illustrated the point that while reproducibility of many spectrographic methods was satisfactory there could still be a large systematic error present. For example, in Table V of his paper, the spread of the mean contents found in each laboratory was $\pm 20\%$ about the mean nickel content of 0·050% although the coefficient of variation found in most laboratories was only 3%.

Mr Bills had already pointed out that some of this error was due to the different calibration graphs used in the various laboratories and to the difficulty of obtaining agreement in the chemical analysis of the standards used. This was true, but there were other effects also which could be recognized as the precision of spectrochemical analysis improved. He had recently been calibrating a vacuum direct reader for the analysis of plain-carbon and low-alloy steels. In the case of many elements the reproducibility was astonishingly good, so good that the error in reading the recorder became significant. In spite of this, it had been found that some points lay off the calibration curve, and reproducibly so. Careful checks had shown that these could not be explained either by inhomogeneity or faulty chemical analysis, and it was presumed that the metallurgical state of the sample or interfering element effects was influencing the result. Fortunately these were only small effects and so far they had not observed any errors greater than would be obtained with normal routine analysis. The precision of modern direct-readers was so great that it was these metallurgical factors which limited the accuracy of analysis of many, if not most, elements. There was a very real need for systematic work on the effect of metallurgical factors on spectrochemical analysis of the type that Mr de Lippa had carried out on manganese in steel.

Mr **Bills** said he agreed that the reproducibility of the technique was obviously a great deal better than its accuracy. It was, however, generally agreed that the accuracy was nevertheless adequate. Apart from the differences already described in drawing up calibration curves there could be no doubt that different units showed different susceptibilities to inter-element effects. Investigation of inter-element effects in relation to different sources was not, however, in the terms of reference of the Study Group. It was being studied in the investigation which Mr de Lippa had already described.

Mr **M. Milbourne** (ICI Metals Division) asked if the excitation index and exposure time were specified and reproducible would the complete procedure be specified and would it then not be necessary to pay much attention to choice of line pair and other parameters usually considered?

Mr **Bills** replied that in general one would imagine that if both excitation index and exposure time were specified the important points of the technique were covered, since the specification of the exposure time should indirectly specify optical speed of the spectrograph and thus tend to eliminate sparking-out effects.

The Chairman commented that it was true that obtaining reproducibility figures of chemical analysis was not easy to arrange, but they could be obtained if the chemist was unaware of it. During a visit to a steel laboratory in the USA he had found that the spectrographer made a practice of putting in a sample of the same material every so often, and he compiled reproducibility figures which were thought to be significant. These were much the same as were obtained by spectrographic methods for carbon, sulphur, and phosphorus.

Mr Bills' paper brought to mind the almost customary expectation of the spectrographer that every spark should be like any other spark. When the electrical parameters had been fixed one made it probable that a certain amount of energy would be released, but the form into which this energy was transformed was only a matter of probability, and it could be that at a particular spark no light of the wavelength wanted was emitted. It was possible to work with source units because a large number of sparks were used in each determination. Dr Kaiser had shown this clearly.

Mr van Someren had mentioned Lacqua's work. This work published in a back number of *Spectrochemica Acta* was, in his opinion, of first-class importance in considering standardization of sources. The actual work was of a restricted nature, but did show that for one substance the quality of spectrum was almost the same for a very wide variety of discharges, provided the parameters were arranged so that similar quantities of energy were emitted in sparks of the same duration of time.

Much more work is needed on this, but it might well be worth it.

WRITTEN CONTRIBUTION

Mr **A. Walker** (John Lysaght's Scunthorpe Works) wrote: Referring to Table V of the paper, the mean content in the particular case of molybdenum varies in the mean from 0·044% to 0·066% which suggests a variation of from 0·040% to 0·070%. This is given as an extreme case but several of the other elements determined have similar conditions. The contention is that chemical analysis done under similar conditions would not give results with a spread as great as that shown in Table V.

Mr **Bills** wrote in reply: The spectrographic method is a comparative and not absolute technique and therefore included in the spectrographic figures is a residual error due to the primary calibration. It must therefore be expected that the accuracy of the spectrographic technique must always be inferior to that of the chemical results on which it is based. Undoubtedly the results could have been improved by closer collaboration between laboratories in the construction of the calibration curves, but the intention of the investigation was to give a reliable comparison between the laboratories under somewhat unfavourable conditions. The results were nevertheless agreed by the committee to be generally acceptable. Under normal operating conditions in a laboratory carrying out regular analyses for residual elements, it would obviously be desirable to carry out regular check chemical analyses. In this way a broadly based calibration would be ensured.

The determination of trace elements

N. W. H. Addink

SYNOPSIS

A short description is presented of the spectrographic methods used in the Philips Research Laboratories. Details of the lines chosen for the determination of residual elements in British Chemical Standard Samples of steel are given with the correction factors used when exposure times are shortened. The coefficient of variation of 13 elements is approximately 15%. An account is also given of the trace elements determined by an impregnated graphite technique in which all elements are taken into solution as perchlorates. Q-factors, expressed in μg, are reported and the recovery of various elements within the range 0·01–1·5 μg are discussed. Auto-electrodeposition on aluminium is described in which a sensitivity of 10^{-4}–10^{-5}% is achieved. The use of complexing agents is also considered. X-ray fluorescence as applied to drillings of steel (coefficient of variation 5%) is discussed together with the effect caused by varying the amounts of some constituents. The use of X-ray fluorescence in trace analysis is described by reference to a method for the determination of a trace of zinc in blood. The sample being in the form of an ash containing more than 50%C, a correction is applied to compensate for scattering effects and depth of penetration of the X-rays. 1764

SPECTROCHEMISTRY

Introduction

THE METHOD OF ANALYSIS applied by our laboratory is one of a complete evaporation of the material to be analysed through a dc carbon arc.[1] There are two factors of significant influence on the intensity of spectral lines obtained from this kind of arc: the temperature of excitation, and the speed of evaporation.

The influence of the temperature of excitation has been discussed thoroughly.[2] A discussion on the speed of evaporation and its influence on the percentage of atoms lost by being thrown out of the arc has also been published.[3] As may be seen from Table I*a* the mean limit of detection (*Q*-arc) for the elements with an ionization potential, V_i, between 7·5 and 8·0 eV amounts to 0·016 μg. For the range 8·0–9·0 eV the limit of detection increases (0·08 μg), and this increase is in accordance with the increase of V_i. A further increase (Table I*b*) may be expected for the elements showing a V_i range between 9 and 11 eV: mean 0·15 μg. The latter value is the average of a much larger range and has been found by studying two groups of elements. Those having a high boiling point show a much lower limit of detection (0·04 μg) than

Paper MG/DD/63/59 of the Spectroscopic Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association received 14 September 1959. The views expressed are the author's and are not necessarily endorsed by the Committee as a whole.

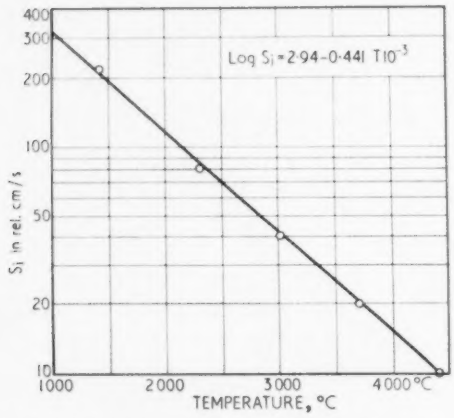
The author is head of the Spectrochemical Department at the Research Laboratories, N. V. Philips' Gloeilampenfabrieken, Eindhoven.

TABLE Ia Results showing the effect of increased ionization potential (V_i), on the limit of detection of elements

Element	Limit of detection, μg	V_i, eV	Boiling point, °C
Ionization potential V_i=7·5–8·0 eV			
Ag	0·01	7·6	1950
Co	0·04	7·9	2900
Cu	0·01	7·7	2300
Fe	0·01	7·9	3100
[Mg(O)	0·004	7·6	3900]
Ni	0·02	7·6	3000
mean	0·02	7·7	2650
range	0·01–0·04	7·6–7·9	1950–3100
Ionization potential V_i=8·0–9·0 eV			
B	0·04	8·3	2700
Bi	0·03	8·0	1500
Ge	0·1	8·1	2700
Sb	0·2	8·6	1400
Si	0·04	8·1	2500
mean	0·08	8·2	2160
range	0·03–0·2	8·0–8·6	1400–2700

TABLE Ib Further results showing the significance of the boiling points of the elements

Element	Limit of detection, μg	V_i, eV	Boiling point, °C
Ionization potential V_i=9–11 eV			
As	0·2	10	600
Au	0·05	9·2	2600
Be(O)	0·01	9·3	3900
Cd	0·1	9·0	770
Hg	0·3	10·4	360
P	0·2	11	380
Pt	0·06	9·0	4300
Zn	0·3	9·4	900
mean	0·15	9·7	1700
range	0·01–0·3	9·0–11·0	360–3900
V_i=9–11 eV (elements of low boiling point)			
As	0·2	10	600
Cd	0·1	9·0	770
Hg	0·3	10·4	360
P	0·2	11	380
Zn	0·3	9·4	900
mean	0·2	10	600
range	0·1–0·3	9·0–11·0	360–900
V_i=9–11 eV (elements of high boiling point)			
Be(O)	0·01	9·3	3900
Au	0·05	9·2	2600
Pt	0·06	9·0	4300
mean	0·04	9·2	3600
range	0·01–0·06	9·0–9·3	2600–4300



1 *Relationship between speed of evaporation and boiling point*

the elements with a low boiling point (0·2 μg) which evaporate at a much higher rate. A high speed of evaporation means a relatively large loss of atoms blown sideways out of the arc. Consequently a relatively small proportion of these atoms is excited and the limit of detection amounts to a high value.

These results indicate that both factors (temperature of excitation and speed of evaporation) are of importance for the intensity of spectral lines originating from a carbon arc.

Speed of evaporation

Depending upon the vapour pressure, elements showing a low boiling point evaporate quickly whereas refractory materials evaporate slowly. The following figures show the relative speed S_i of evaporation in cm/s.

	Boiling point, °C	S_i, cm/s
Te	1390	220
Cu	2300	80
Ni	3000	75
Fe	3100	50
$Th(O_2)$	4400	10

Figure 1 shows the relationship between boiling point T and S_i, which can also be expressed in the following formula:

$$\log S_i = 2{\cdot}94 - 0{\cdot}44 \times 10^{-3} T$$

In most cases this relationship need not be taken into account; and under the conditions chosen each element or compound evaporates at its 'own speed'. Although any deviation from this 'own speed' is in general of no importance, it was thought worthwhile in the case of the following materials to mention some exceptions where there exists a relatively large difference between the boiling points of major and minor components.

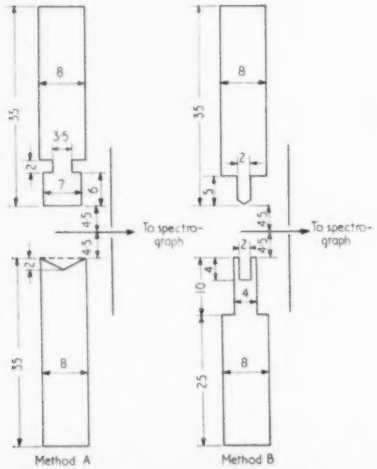
1. Aluminium evaporates according to its boiling point (1800°C) at a rate of 140 cm/s; however, it has been found experimentally that S_i amounts to 90 cm/s, corresponding to a boiling point of 2250°C, which is the boiling point of Al_2O_3. In fact the presence of this material has been indicated by X-ray diffraction.

2. Lead evaporates from metals at a rate of S_i = 180 cm/s, also from iron and copper. From aluminium it evaporates via the oxide-phase at a rate of 80 cm/s. This means that results obtained are too high (according to a ratio of 180/80). This is found to be in accordance with experimental results.

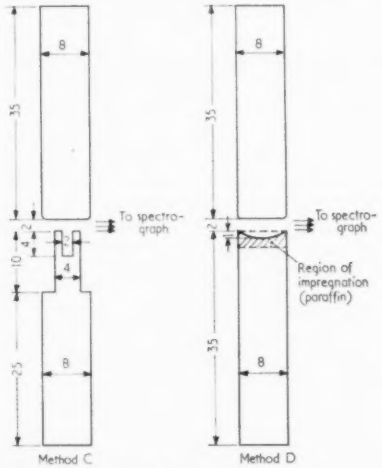
3. The evaporation of copper from steels, lead, tin, and copper takes place at a rate of $S_{iCu} = \sim 80$ cm/s; from zinc it evaporates (partly selectively) with a speed of ≤ 350 cm/s and from selenium with a S_i of about 400 cm/s. For both copper resonance lines the correction factors measured experimentally and calculated are as follows:

Matrix	Correction factor, calculated	Correction factor, experimental
Fe, Pb, Sn, Cu	1	1
Zn	$\leq 350/80 = \leq 4$	2
Se	400/80 = 5	4

4. Magnesium evaporates from metals at a rate three times as great as it does as the oxide from an oxidic mixture or compound. This is in accordance with its rate of evaporation at 2200°C, where there is a reaction between the oxide and carbon, S_i amounts to 90 cm/s, whereas S_i of the metal itself boiling at



Method A: 5 mg, 7′ K-arc, normally used K-factors
Method B: 5 mg, 4′, modified K-factors



Method C: 10 mg, 3 × 1′ Q-arc, Q-factors
Method D: 0·1 ml solution, 1′

2 *Shapes of electrodes*

TABLE II *K*-factors* used with arcing conditions if method A used (or method B if mentioned) and *Q*-factors used with arcing conditions of method C

	Wavelength, Å	K, %	*I*	
Al	3082·15	0·011		
		0·016	10	
	2575·10	0·14		
B	2497·73	0·0047	1–10	
	2496·77	0·012	1–10	
Co	2521·36	0·019	3	
		0·04	20	
	3044·00	0·025	3	
		0·05	20	
Cr	2677·15 II	0·05		
	2860·93 II	0·23		
Cu	3273·96	0·0007	1	
		0·0012	5	
		0·0015	10	
		0·0019	20	
		0·0024	40	
	2824·36	0·25		
Mo	3170·34	0·035†		(×0·31 in case of method B)
	2816·15 II	0·2		
Nb	3094·18 II	0·16		
	3194·97 II	0·26		(×0·29 in case of method B)
	2883·17	0·49		
	3028·44 II	0·8		
Ni	3414·76	0·0025		
	3003·62	0·017		
	2992·59	0·1		
Sn	3175·01	0·017		
	2839·98	0·017		
Ti	3241·98 II	0·02		
	2646·63	0·27		
V	3185·39	0·02		
	3130·26 II	0·06		
	2952·08 II	0·12		(×0·7 in case of method B)
	2882·50 II	0·16		
	2884·78 II	0·20		
W	2946·98	1·5		(×0·13 in case of method B)
	2896·4	2·0		
Zr	3430·53 II	0·1		(×0·3 in case of method B)

Q-factors: method C for steel	Wavelength, Å	*Q*, %	*I*
Nb	3094·18 II	0·03	
	3194·97 II	0·038	
Pb	2833·06	0·004	1
		0·006	2
Ti	3241·98 II	0·005	
W	2946·98	0·037	
Zr	3438·23 II	0·007	

* Valid for all kinds of quartz prism spectrograph
† Correction for coinciding iron line

TABLE III Spectrochemical determination of aluminium in BCS steel nos.271–277; range 0·008–0·068%, mean value 0·033%Al

Steel	Certificate, %	Aluminium, % 1	2	3	Mean, %
BCS 271	0·008				
A		0·010	0·006[4]	0·008[9]	0·008[4]
B		0·007	0·005	0·006[5]	0·006[2]
BCS 272	0·068				
A		0·089	0·074	0·086	0·083
B		0·057	0·090	0·076	0·074
BCS 273	0·060				
A		0·080	0·069	0·086	0·078
B		0·063	0·061	0·072	0·065
BCS 274	0·032				
A		0·043	0·023	0·065	0·044
B		0·025	0·039	0·037	0·034
BCS 275	0·020				
A		0·035	0·018	0·023	0·025
B		0·021	0·020	0·028	0·023
BCS 276	0·025				
A		0·046	0·021	0·031	0·033
B		0·021	0·020	0·021	0·021
BCS 277	0·015				
A		0·025	0·020	0·026	0·024
B		0·016	0·016	0·014	0·015

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	29	0·0097
B	15	0·0049

TABLE IV Spectrochemical determination of boron in BCS steel nos.271–276; range 0·002–0·013%, mean value of range 0·0055%B

Steel	Certificate, %	Boron, % 1	2	3	Mean, %
BCS 271	0·013				
A		0·013	0·015	0·015	0·014[3]
B		0·016	0·017	0·017	0·016[7]
BCS 272	0·004				
A		0·004[5]	0·004[2]	0·004[6]	0·004[4]
B		0·004[4]	0·005[9]	0·005	0·005[1]
BCS 273	0·002				
A		0·002[6]	0·002[4]	0·003[3]	0·002[8]
B		0·001	0·003[5]	0·002[8]	0·002[1]
BCS 274	0·008				
A		0·009[6]	0·012	0·011	0·011
B		0·008[7]	0·010	0·008[9]	0·009[2]
BCS 275	0·002				
A		0·001[6]	0·001[3]	0·001[7]	0·001[5]
B		...	0·002[2]	0·001[5]	0·001[9]
BCS 276	0·004				
A		0·003[2]	0·006	0·004[1]	0·004[4]
B		0·002[5]	0·006	0·003[5]	0·004

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	13	0·0007
B	20	0·001

1 100°C, amounts to 280 cm/s; the increase of speed of evaporation with a factor of 280/90=3 leads to a decrease of the number of atoms excited in the arc and of the intensity of the corresponding spectral lines. In practice it was found that results had to be multiplied by 2·5.

Some exceptional cases have been given here. In most cases, however, elements evaporate at their 'own speeds'.

Arcing conditions

Method A (*see* Fig.2, A): 5 mg of the sample; constant gapwidth 9 mm; arcing time 7 min.

TABLE V Spectrochemical determination of cobalt in BCS steel nos.271–277; range 0·015–0·25%, mean value of range 0·098%Co

Steel	Certificate, %	Cobalt, % 1	2	3	Mean, %
BCS 271	0·015				
A		0·019	0·015	0·018	0·017
B		0·015	0·019	0·021	0·018
BCS 272	0·25				
A		0·23	0·21	0·25	0·23
B		0·36	0·28	0·36	0·33
BCS 273	0·021				
A		0·024	0·024	0·028	0·025
B		0·030	0·026	0·029	0·028
BCS 274	0·19				
A		0·15	0·21	0·21	0·19
B		0·21	0·22	0·19	0·21
BCS 275	0·060				
A		0·057	0·055	0·062	0·058
B		0·057	0·055	0·058	0·057
BCS 276	0·027				
A		0·029	0·032	0·034	0·032
B		0·031	0·031	0·031	0·031
BCS 277	0·125				
A		0·11	0·12	0·12	0·117
B		0·14	0·13	0·13	0·133

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	10	0·01
B	8	0·008

TABLE VI Spectrochemical determination of chromium in BCS steel nos.271–277; range 0·025–0·185%, mean value of range 0·089%Cr

Steel	Certificate, %	Chromium, % 1	2	3	Mean, %
BCS 271	0·045				
A		0·050	0·054	0·052	0·052
B		0·053	0·049	0·048	0·050
BCS 272	0·025				
A		0·023	0·027	0·019	0·023
B		0·024	0·028	0·026	0·026
BCS 273	0·075				
A		0·066	0·076	0·070	0·071
B		0·074	0·061	0·070	0·068
BCS 274	0·185				
A		0·15	0·18	0·17	0·17
B		0·22	0·185	0·17	0·19
BCS 275	0·165				
A		0·16	0·17	0·16	0·163
B		0·195	0·16	0·16	0·172
BCS 276	0·10				
A		0·08	0·10	0·088	0·09
B		0·12	0·11	0·095	0·11
BCS 277	0·03				
A		0·023	0·030	0·013	0·022
B		0·020	0·026	0·021	0·022

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	10	0·009
B	13	0·012

Method B (*see* Fig.2, B): 5 mg of the sample; constant gapwidth 9 mm; arcing time 4 min.

Method C (*see* Fig.2, C): 10 mg of the sample; constant gapwidth 2 mm; arcing time 3 min, taken in 3 steps of 1 min.

Method D (*see* Fig.2, D): 0·1 ml of a solution; constant gapwidth 2 mm; arcing time 1 min.

The electrodes have been prepared from National Carbon Co. graphite; the current is 10 A during arcing.

TABLE VII Spectrochemical determination of copper in BCS steel nos.271–277; range 0·01–0·21%, mean value of range 0·095%Cu

Steel	Certificate, %	Copper, % 1	2	3	Mean, %
BCS 271	0·01				
A		0·009	0·006	0·007	0·007
B		0·013	0·005[4]	0·012	0·01
BCS 272	0·015				
A		0·013	0·011	0·011	0·012
B		0·015	0·011	0·028	0·018
BCS 273	0·165				
A		0·165	0·16	0·15	0·16
B		0·077	0·061	0·17	0·10
BCS 274	0·04				
A		0·030	0·039	0·050	0·040
B		0·050	0·046	0·056	0·051
BCS 275	0·21				
A		0·23	0·17	0·17	0·19
B		0·18	0·10	0·21	0·16
BCS 276	0·125				
A		0·125	0·10	0·09	0·105
B		0·16	0·06	0·13	0·12
BCS 277	0·10				
A		0·095	0·081	0·080	0·085
B		0·098	0·058	0·095	0·084

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	17	0·016
B	42	0·04

TABLE VIII Spectrochemical determination of lead in BCS steel nos.271–277; range 0·0025–0·0085%, mean value of range 0·005%Pb

Steel	Certificate, %	Lead, % 1	2	3	Mean, %
BCS 271	0·0025				
C		0·0031	...	0·0036	0·002[3]
BCS 272	0·003				
C		0·0034	0·0036	0·0037	0·003[6]
BCS 273	0·003				
C		0·0036	0·003	0·0028	0·003
BCS 274	0·0085				
C		0·010	0·005	0·005[5]	0·007
BCS 275	0·005				
C		0·006	0·004	0·004[5]	0·005
BCS 276	0·0065				
C		0·010	0·005[5]	0·004	0·006[5]
BCS 277	0·0065				
C		0·007[5]	0·008[5]	0·003[5]	0·006[5]

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
C	32	0·0016

Determination of the intensity *I* of spectral lines

The light-source slit is chosen in such a way using the masking assembly that a spectrum obtained from 5 mg of iron by applying method A shows a density of 0·3 (corresponding to a (relative) intensity of 4) for the following iron lines: 2645·42 I, 2667·91 I, 2883·70 II+ 2883·73 I, and 2815·50 I. Normally the slitwidth of the light-source slit is about 0·5 mm (length of the slit 15 mm).

A slope of about 45° of the characteristic curve of the photographic emulsion is most desirable for this general method of analysis. In the author's laboratory

TABLE IX Spectrochemical determination of molybdenum in BCS steel nos.271–277; range 0·015–0·19%, mean value of range 0·098%Mo

Steel	Certificate %	Molybdenum, % 1	2	3	Mean, %
BCS 271	0·19				
A		0·16	0·20	0·15	0·17
B		0·24	0·19	0·18	0·20
BCS 272	0·17				
A		0·19	0·16	0·22	0·19
B		0·16	0·15	0·18	0·16
BCS 273	0·045				
A		0·040	0·033	0·045	0·039
B		0·042	0·037	0·037	0·039
BCS 274	0·07				
A		0·090	0·057	0·10	0·082
B		0·084	0·077	0·067	0·076
BCS 275	0·095				
A		0·14	0·13	0·14	0·14
B		0·096	0·13	0·096	0·10
BCS 276	...				
A		...	...	...	...
B		0·004	0·004	0·002	0·003
BCS 277	0·015				
A		0·014	0·013	0·003	0·010
B		0·012	0·014	0·009	0·012

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	18	0·017
B	12	0·012

TABLE X Spectrochemical determination of nickel in BCS steel nos.271–277; range 0·015–0·235%, mean value of range 0·1%Ni

Steel	Certificate %	Nickel, % 1	2	3	Mean, %
BCS 271	0·015				
A		0·009	0·007	0·007	0·008
B		0·009	0·007	0·008	0·008
BCS 272	0·035				
A		0·031	0·034	0·040	0·035
B		0·032	0·032	0·038	0·034
BCS 273	0·03				
A		0·040	0·037	0·042	0·040
B		0·034	0·035	0·035	0·035
BCS 274	0·13				
A		0·13	0·13	0·14	0·13
B		0·13	0·12	0·11	0·12
BCS 275	0·08				
A		0·089	0·082	0·081	0·084
B		0·076	0·078	0·077	0·077
BCS 276	0·18				
A		0·17	0·18	0·18	0·18
B		0·165	0·155	0·15	0·16
BCS 277	0·235				
A		0·20	0·22	0·23	0·22
B		0·20	0·20	0·21	0·20

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	7	0·0068
B	6·5	0·0066

Kodak SA2 plates are used. They are developed in such a way that the following relationship exists:

Density	Intensity (relative)
0·03	0·5
0·07	1
0·15	2
0·22	3
0·30	4
0·40	6
0·52	8
0·64	12
0·77	16
1·04	32

However, this is not critical.

Furthermore, for the sake of speeding up intensity measurements the s.p.d. scale is applied. The s.p.d. scale has the following advantages:

TABLE XI Spectrochemical determination of tin in BCS steel nos.271–276; range 0·015–0·11%, mean value of range 0·045%Sn

Steel	Certificate, %	Tin, % 1	2	3	Mean, %
BCS 271	0·11				
A		0·07	0·055	0·069	0·065
B		0·10	0·066	0·097	0·088
BCS 272	0·02				
A		0·017	0·019	0·015	0·017
B		0·015	0·019	0·024	0·019
BCS 273	0·065				
A		0·058	0·044	0·047	0·050
B		0·043	0·046	0·063	0·051
BCS 274	0·02				
A		0·027	0·021	0·028	0·025
B		0·022	0·024	0·026	0·024
BCS 275	0·04				
A		0·045	0·032	0·034	0·037
B		0·037	0·037	0·039	0·038
BCS 276	0·015				
A		0·017	0·014	0·014	0·015
B		0·018	0·015	0·016	0·016

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	15·5	0·007
B	16	0·0075

TABLE XII Spectrochemical determination niobium in BCS steel nos.271 and 274–77; range 0·04–0·19%, mean value of range 0·08%Nb

Steel	Certificate, %	Niobium, % 1	2	3	Mean, %
BCS 271	?				
B		0·22	0·20	0·16	0·19
C*		0·15	0·20	0·11	0·15
BCS 274	?				
B		0·091	0·085	0·071	0·082
C*		0·076	0·060	0·050	0·062
BCS 275	?				
B		0·056	0·045	0·051	0·051
C*		0·065	0·067	0·030	0·054
BCS 276	?				
B		0·077	0·074	0·077	0·076
C*		0·062	0·11	0·056	0·076
BCS 277	?				
B		0·040	0·041	0·049	0·043
C*		0·044	0·055	0·030	0·043

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
B	12	0·01
C	35	0·03

* Nb evaporates during the 2nd and 3rd minute

(i) qualitative examination and quantitative determination are carried out at the same time
(ii) the s.p.d. scale corrects automatically for background
(iii) only faint lines are measured (up to a maximum density of 0·5 or 0·6); in this way the effect of self absorption is avoided in many cases.

S.p.d. scales are calibrated by comparison with about 120 spectral lines photographed on a masterplate once and for all photometrically measured (background corrections included).[9]

K-factors

For K-factors (K = concentration/intensity) used the reader is referred to Table II.

It seems likely that the increase in the temperature of the crater (3500°C, method A; 4000°C, method B)

TABLE XIII Spectrochemical determination of titanium in BCS steel nos.271–277; range 0·005–0·095%, mean value of range 0·01%Ti

Steel	Certificate, %	Titanium, % 1	2	3	Mean, %
BCS 271	0·005				
A		0·004	0·008	0·006	0·006
B		0·005	...	...	...
BCS 272	0·015				
A		0·013	0·005	0·015	0·011
B		0·017	0·016	0·021	0·018
BCS 273	0·070				
A		0·055	0·042	0·065	0·054
B		0·077	0·069	0·076	0·074
BCS 274	0·095				
A		0·091	0·071	0·082	0·081
B		0·12	0·13	0·13	0·13
BCS 275	0·035				
A		0·037	0·035	0·033	0·035
B		0·042	0·042	0·042	0·042
BCS 276	0·005				
C		0·005	0·005	0·005	0·005
BCS 277	0·035				
A		0·031	0·028	0·031	0·030
B		0·033	0·033	0·037	0·034

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	15	0·0015
B	7	0·0007

TABLE XIV Spectrochemical determination of tungsten in BCS steel nos.273–277; range 0·04–0·28%, mean value of range 0·14%W

Steel		Certificate, %	Tungsten, % 1	2	3	Mean, %
BCS 273		0·28				
	B		0·30	0·14	0·19	0·21
	C*		0·11	0·22	0·20	0·18
BCS 274		0·04				
	C*		0·015	...	...	...
BCS 275		0·05				
	C*		0·04	0·06	...	0·03
BCS 276		0·205				
	B		0·17	0·165	0·13	0·155
	C*		0·09	0·21	0·18	0·16
BCS 277		0·125				
	B		0·12	0·11	0·13	0·12
	C*		0·08	0·13	0·16	0·12

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
B	20	0·028
C	39	0·055

* W evaporates during the 2nd and 3rd minute

is responsible for the correction factors f when method B has been applied instead of method A:

	f	Boiling point, °C Metals	Carbides
W	0·13	5900	6000
Nb	0·29	5700	?
Zr	0·3	>2900	5100
Mo	0·31	3700	4500
V	0·7	3000	3900

Tables III–XVI show the results of the spectrochemical determinations of the elements Al, B, Co, Cr, Cu, Pb, Mo, Ni, Sn, Nb, Ti, W, V, and Zr present in British Chemical Standard samples nos.271–277.

Three independent determinations (in duplicate) have been carried out, their mean value has been given and also the standard deviation σ or coefficient of variation with reference to the mean value of the range.

Standard deviation

As determined from three independent determinations in duplicate of seven BCS samples the standard deviations are given using methods A, B, and C below. The results of X-ray fluorescence measurements are given for comparison.

Range, %	Method A	Method B	Method C	X-ray fluorescence
Al 0·008–0·068	29	15	...	...
B 0·001–0·013	13	20	...	...
Co 0·015–0·25	10	8	...	...
Cr 0·025–0·185	10	13	...	1·7
Cu 0·01 –0·21	17	42	...	5
Mo 0·015–0·19	17·5	12	...	3
Ni 0·015–0·235	7	6·5	...	3·5
Pb 0·002–0·008	...	...	30	...
Sn 0·015–0·11	15	16	...	7
Ti 0·005–0·095	15	7	...	1
V 0·015–0·105	10	9	...	2·5
W 0·04 –0·28	...	20	31	...
Zr tr –0·045	...	17	~26	6·5
Nb 0·04 –0·19	...	12	35	20
Coefficient of variation	14%	16%	30%	5·5%

As a comparison the standard deviation of the determination of the following elements (16 independent determinations in duplicate) in nickel by means of

TABLE XV Spectrochemical determination of vanadium in BCS steel nos.273–277; range 0·015–0·105%, mean value of range 0·06%V

Steel		Certificate, %	Vanadium, % 1	2	3	Mean, %
BCS 273		0·045				
	A		0·042	0·042	0·067	0·050
	B		0·040	0·044	0·048	0·044
BCS 274		0·015				
	A		0·016	0·015	0·018	0·016
	B		0·017	0·022	0·019	0·019
BCS 275		0·05				
	A		0·067	0·067	0·063	0·066
	B		0·051	0·056	0·047	0·051
BCS 276		0·055				
	A		0·080	0·073	0·089	0·081
	B		0·058	0·056	0·055	0·056
BCS 277		0·105				
	A		0·128	0·120	0·115	0·12
	B		0·10	0·098	0·093	0·10

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
A	10	0·006
B	9	0·0053

'the low-voltage spark' on an Applied Research Laboratories production control Quantometer are given here:

	%	Coefficient of variation, %	Standard deviation
Si	0·016	6	0·001
Mn	0·009	19	0·0017
Fe	0·04	11	0·0045
Mg	0·08	2·5	0·002
Cu	0·005	3	0·00014
	Mean	8	

Further modifications of technique

Many attempts have been made to alter the temperature of excitation in the carbon arc by adding elements either showing a low ionization potential, V_i, resulting in an increase of the intensity of lines of these elements (the alkalis for instance), or showing a high value of V_i resulting in an increase of the line intensity of elements difficult to excite (the transition elements).

TABLE XVI Spectrochemical determination of zirconium in BCS steel nos.271–277; range 0·005–0·045%, mean value of range 0·024%Zr

Steel		Certificate, %	Zirconium, % 1	3	3	Mean, %
BCS 271		0·045				
	B		0·039	0·040	0·042	0·040
	C*		0·042	0·042	0·050	0·046
BCS 272		0·030				
	B		0·025	0·046	0·032	0·034
	C*		0·032	0·029	0·040	0·034
BCS 273		trace				
	B		<0·007	<0·008	...	<0·005
BCS 274		0·005				
	B		<0·020	<0·029	<0·022	<0·024
BCS 275		0·015				
	B		<0·029	<0·027	<0·035	<0·030
BCS 276		0·005				
	B		<0·022	<0·026	<0·018	<0·022
BCS 277		0·040				
	B		0·044	0·042	0·042	0·043
	C*		0·053	0·054	0·062	0·056

	Coefficient of variation, σ_{rel}, %	Standard deviation, σ_{abs}, %
B	17	0·004
C	>12	>0·003

* Zr evaporates during the 2nd minute

TABLE XVII Comparison of various methods for determining impurities in sodium chloride, germanium, steel, and zinc sulphide

	Wet chemical	Spectrographic + Al method	Spectrographic method Direct
NaCl(F)	$1{\cdot}3\times10^{-4}$%Pb	1×10^{-4}%Pb	$<7\times10^{-4}$%Pb
NaCl(M)	$1{\cdot}2\times10^{-5}$%Pb	3×10^{-5}%Pb	$\ll8\times10^{-4}$%Pb*
ZnS(L 2260)	$2{\cdot}5\times10^{-4}$%Pb	$3{\cdot}5\times10^{-4}$%Pb	$\sim3\times10^{-4}$%Pb
Steel(NBS 130)	?	7×10^{-4}%Sn	$\ll2\times10^{-3}$%Sn
ZnS(Q)	?	$4{\cdot}5\times10^{-5}$%Cu	$<5\times10^{-5}$%Cu†
ZnS(Q)	?	1×10^{-3}%Pb	1×10^{-3}%Pb
ZnS(Q)	?	$2{\cdot}5\times10^{-6}$%Ag	$\ll2\times10^{-5}$%Ag
ZnS(Q)	?	7×10^{-5}%Sn	$\ll3\times10^{-4}$%Sn
Germanium	$(5\text{–}8)\times10^{-5}$%Sb‡	$\approx(3\text{–}5)\times10^{-5}$%Sb	$\ll1\times10^{-3}$%Sb

* Resonance line of the element in question is absent ($\ll$)
† Resonance line is present, but faintly visible; a part of the intensity can be attributed to impurity of the anode ($<$)
‡ This figure originates from physical measurements

The improvement of the detectability by a factor of about 5–8 is of the same magnitude as an increase of the temperature by burning the arc in an argon–oxygen atmosphere.[2]

PRE-CONCENTRATION METHODS

It is often necessary to increase the sensitivity of a method by using pre-concentration techniques in which case the following may be useful:

Chemical methods

(i) Selective volatilization of the major component ($Ge\rightarrow GeCl_4\uparrow$)[4]
(ii) Extraction methods; complexing agents.

Electrochemical methods

(i) Internal electrolysis by partly dissolving in an acid solution[5]
(ii) Auto-electrodeposition on a base metal like aluminium (Al-method)
(iii) Electrolysis into mercury.[6]

TABLE XVIII Summary of Q_{C10_4} factors using solution method

Wavelength, Å		Q_{C10_4}, μg	Wavelength, Å		Q_{C10_4}, μg
Ag 3280		0·009	Mn 3044		0·8
3382		0·021	2595		4·8
Al 3092		0·02 $I=6$	3070		6·5
		0·04 $I=9$	2738		54
3082		0·04 $I=3$	Ni 3414		0·25
		0·07 $I=6$	3002·5		0·33
2575		1·4	3050·8		0·37
2567		1·6	3003·6		0·53
2660		1·8	2992·6		2·7
Bi 3067		0·042	2943·9		2·7
Cd 3261		0·55	3105·5		8·4
Co 2521		0·33	3217·8		18·5
3044		0·49	Pb 2833		0·2
2627		12·8	2614		0·38
3177		28	2873		0·8
Cr 2677	II	0·15	2663		0·9
2849	II	0·28	2823		1·5
3015		0·4	2577		1·6
2860	II	1·1	Sb* 2598		0·8
2653		2·9	2877		2
Cu 3247		0·015	Ti 3242	II	0·24
3274		0·027	3152	II	5·3
2824		4·9	2842	II	6
Fe 2599	II	0·085	2646		7·4
2994·4		0·37	2605		19
2625	II	0·48	V 3138·98		0·43
2936·9		0·50	3185·39		0·47
2628	II	0·54	3183·40		0·7
Mn 2576	II	0·011	3130	II	1·2
2798		0·015	2952	II	1·3
2801		0·022	Zn 3345·0		0·5
2933	II	0·061			

* Sulphate

The aluminium method

This method has been tried on the determination of lead in sodium chloride: 10 g of NaCl are dissolved in 70 ml HCl (1N); 400 mg of filings of highly pure aluminium (99·99%) are added, as well as an extremely small amount of $HgCl_2$. The solution is kept warm on a steam bath for 2 h or more. Afterwards the residual amount of aluminium is separated either by filtering or by centrifuging off. The following figures have been found (analysis of NaCl–F):

	Residual amount of Al, mg,	Pb in residue, %	mg	Pb present in 10 g NaCl, mg
Experiment 1	23	0·05	0·0115	0·0094
Experiment 2	33	0·04	0·0132	0·0111
Blank	30	0·007	0·0021	mean 0·0103

This means that the sodium chloride contains 1×10^{-4}%Pb. Spectra were taken of the same sample of sodium chloride directly, resulting in the reporting of less than 7×10^{-4}%Pb. Wet-chemically $1{\cdot}3\times10^{-4}$%Pb was found.

In the same way steel, zinc sulphide, and germanium were analysed: 1150 mg of steel (NBS 130); 400 mg of Al; the residual Al amounted to 77 and 44 mg respectively; 2 g ZnS were dissolved in 40 ml HCl (2N); afterwards 30 ml HCl (1N), 400 mg Al, and a trace of $HgCl_2$ were added; the residual amount of Al was 32 mg.

2 g Ge were dissolved in aqua regia and afterwards heated with H_2SO_4 and HF; an amount of HCl (2N) was added; total volume 80 ml; 400 mg Al; residual amount of Al 20·9 mg. This method of working was repeated many times. Results were not always reliable. Table XVII gives a summary of some results obtained.

The analysis of solutions

The following method has been developed to enable the use of wet-chemical pre-concentration methods. There are various complexing agents separating impurities from the major constituents. A complex metal organic compound is formed, which can be easily decomposed by perchloric acid. In this way dilute solutions of metal perchlorates are obtained, which can be analysed spectrochemically.

In practice 0·1 ml is placed on the top of the graphite anode (*see* Fig.2, D), which is made impenetrable to the solution by paraffin wax (some drops of a solution of petrol ether (bp 60–80°C) containing 5% paraffin liquefying at 70°C, are placed on the electrode and evaporated). The solution of perchlorates is dried

TABLE XIX Synthetic recoveries using spectrographic solution method

Placed on the anode μg	0·012	0·025	0·05	0·10	0·12	0·15	0·25	0·30	0·50	1·5
Recovered Ag	0·016	0·03	0·06 0·05[2] 0·06 0·04[5]			0·16 0·17				
Al	0·01[4]			0·10 0·07 0·08 0·09				0·4 0·4		
Bi		0·02[4]	0·04[2] 0·04[8] 0·06[3]			0·13 0·14				
Cd							0·17		0·6[6] 0·3[8] 0·5	1·6 1·2
Cu	0·016	0·029	0·05[5] 0·06[4] 0·05[5] 0·05			0·11 0·16				
Fe					0·13		0·29		0·4[5] 0·6[7] 0·5 0·5	1·6 1·5[5]
Mn	0·012	0·032	0·05[5] 0·05[3] 0·05 0·05[1]			0·13 0·15[8]				
Ni					0·1		0·26		0·4[5] 0·4[3] 0·7 0·5[5]	1·3 1·8
Pb					0·1[6]		0·24		0·5 0·4[7] 0·5 0·5[2]	1·6 1·3[5]
Zn									0·6 0·4[3] 0·4[7]	1·5[5] 1·2[5]

under an infra-red lamp and arced to completion during 1 min. Q_{C10_4}-factors have been summarized in Table XVIII.

TABLE XX X-ray fluorescence values of 2θ and wavelengths of lines and backgrounds measured

	Line		Background		Excitation
	2θ ° ′	λ, Å	2θ ° ′	λ, Å	
SnK_α	8 44	0·492	9 0	0·525	50–18-vacuum
MoK_α	12 18	0·710	11 5	0·674	,,
NbK_α	12 85	0·748	13 4	0·777	,,
CuK_α	26 67	1·542	27 4	1·583	,,
NiK_α	28 73	1·659	27 4	1·583	,,
CrK_α	40 08	2·291	39 0	2·232	,,
VK_α	44 01	2·505	43 0	2·450	,,
TiK_α	48 56	2·749	47 5	2·693	,,
MnK_α	36 66	2·103	38 6	2·210	,,
ZrK_α	13 54	0·788	14 0	0·814	,,
FeK_β	30 47	1·757	27 4	1·583	16–6–1 atm

TABLE XXI Results of measurements of the intensity of the line FeK_β

Steel	I_{Fe} counts/s	Correction-factor
BCS 271	387·3	1·118
272	472·2	0·915
273	463·9	0·932
274	426·2	1·01
275	429·9; 429·0; 435·6; 424·2	1·00
276	409·7	1·056
277	445·4	0·97

Iron has been considered as internal standard
Intensities of impurity lines have been corrected with a factor equal to $430/I_{Fe}$

Where chemical concentration techniques are used it is necessary to know the recovery values for the elements and Table XIX shows some results. Each

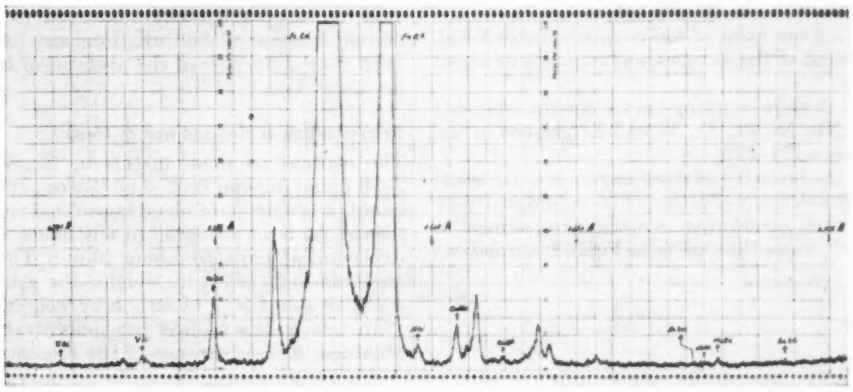
TABLE XXII The determination of the standard deviation from X-ray fluorescence-measurements of various impurities in BCS steel no.275

date	counts/s 13/12	15/12	16/12	17/12		C.V., %
Sn	4·4	5·1	4·9	4·9		7
Mo	14·4	15·3	15·2	15·2		3
Nb	3·2	3·5	4·5	4·9		20
Cu	114·6	120·5	126·1	122·2		5
Ni	57·9	55·4	59·1	59·3		3·5
Cr	206·1	205·4	212·5	210·1		1·7
V	25·7	26·3	26·9	25·8		2·5
Ti	9·3	9·2	9·3	9·4		1
Mn	416·1	426·8	440·2	431·0		3
Zr	5·5	5·7	5·5	5·0		6·5
Fe	429·0	429·9	435·6	424·2	mean	5·5

TABLE XXIII The dependence of K_{zinc} (=concentration of zinc in wt-%/intensity of ZnK_α in counts/s) of the ash-content of human blood, in X-ray fluorescence analysis

Ash content, %	K_{zinc}, %	Ash-content × 100 K_{zinc}, zinc, ppm
2·0	0·00032	0·064
2·5	0·00030[5]	0·076[5]
3·0	0·00029	0·087
3·5	0·00028	0·098
4·0	0·00026[5]	0·106
4·5	0·00025	0·113
5·0	0·00024	0·120

The last column has been mentioned here for practical purposes: multiplication of this figure with the intensity in counts/s (V measured on our instrument), gives the concentration of the element in ppm of blood (the intensity of the ZnK_α line has been measured at 1·437Å, background at 1·407Å; excitation: 40 kV; 20 mA; vacuum).



3 *Qualitative X-ray fluorescence analysis of BCS no.275: excitation source: W-tube, 50 kV, 18 mA, vacuum*

value is the mean of measurements in triplicate. In many cases four independent determinations (in triplicate) have been carried out. It will be understood that impurities originating from the graphite electrodes can influence the results.

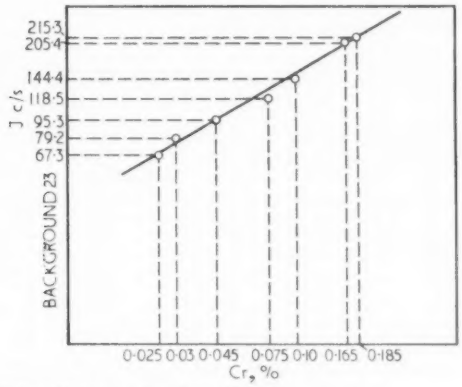
X-RAY FLUORESCENCE ANALYSIS

Steels

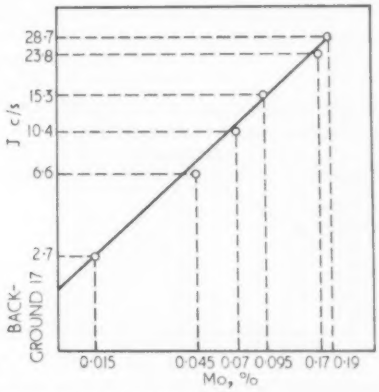
In general this kind of analysis is carried out by the exposure of a flat surface. The BCS samples are in the form of small drillings. First of all the reproducibility of the measurements has been determined. The standard deviation of the estimation of various elements has already been given (*see* also Table XXII).

Figure 3 shows a qualitative impression, read from the recording console, of a BCS sample no.275. Table XX shows the chosen lines and backgrounds measured. All measurements have been carried out with a Philips X-ray fluorescence apparatus, working at 50 kV, 18 mA (the light path partly *in vacuo*).

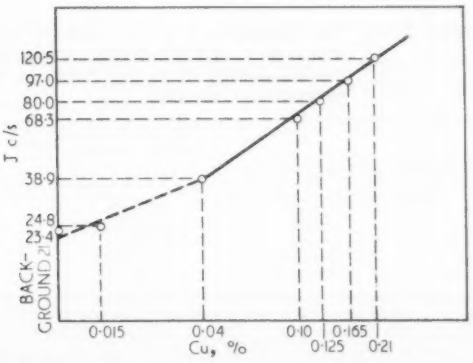
Because of the greater inconsistency of the irradiated surface of drillings as compared with flat-surface



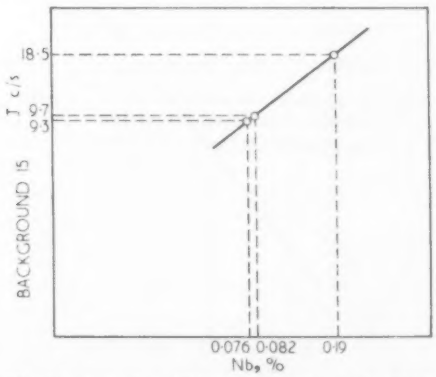
4 *Calibration curve for chromium*



6 *Calibration curve for molybdenum*



5 *Calibration curve for copper*

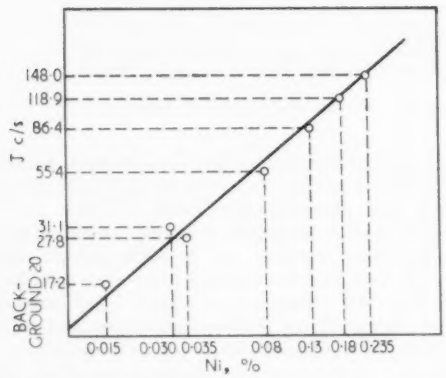


7 *Calibration curve for niobium (spectrochemical values)*

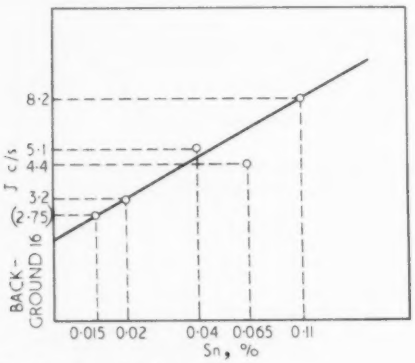
samples normally used, all iron intensities have been corrected to a mean value of 430 counts/s (Table XXI). The iron content of the samples was constant at about 98·5%.

Figures 4–12 show working curves for the elements Cr, Cu, Mo, Nb, Ni, Sn, Ti, V, and Zr present in the BCS sample nos.271–277.

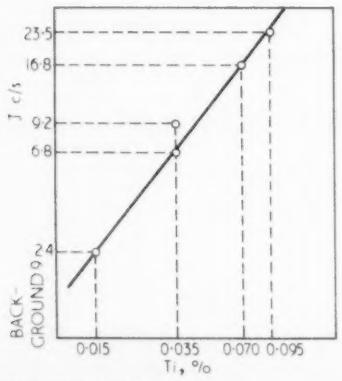
Although the linearity of these curves is quite satisfying the inter-element effect must be considered very carefully. A steel, containing no manganese, seemed to contain 0·96% copper according to Fig.5. It turned out that the copper content amounted to 0·02%. This 50-fold increase of the CuK_α intensity (at ~1·5Å) has been caused by lack of the absorption by manganese (at <1·9 Å).



8 *Calibration curve for nickel*



9 *Calibration curve for tin*

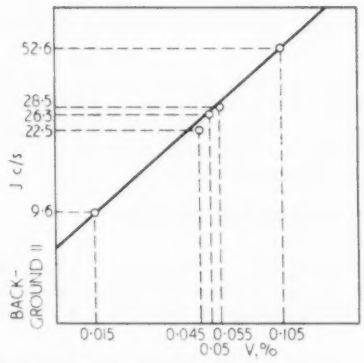


10 *Calibration curve for titanium*

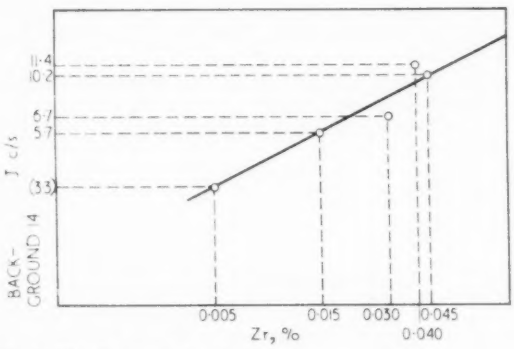
Determination of zinc and iron in blood

The content of these metals in blood amounts to 2–15 ppm zinc and 0·02–0·05% iron. It is difficult to handle a few drops of blood because of clotting. Therefore about 5 ml are dried (a few hours at 130°C) and dry-ashed at 490°C for about 20 min. The ash-content amounts to $2\frac{1}{2}$–$4\frac{1}{2}$% by weight; the ash is black and contains about 50% of carbon by weight.

In this way a 25-fold pre-concentration has been obtained. A disadvantage of the presence of carbon is



11 *Calibration curve for vanadium*

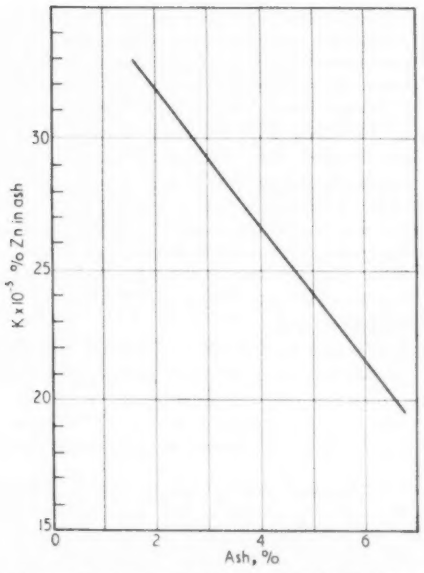


12 *Calibration curve for zirconium*

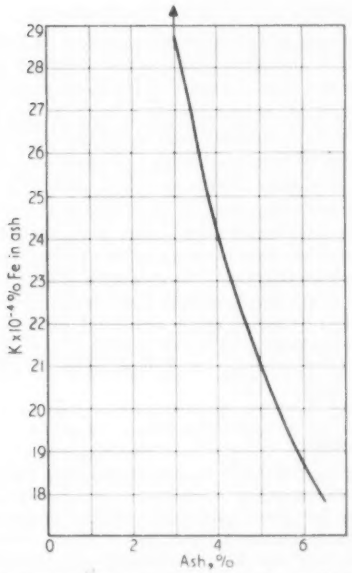
TABLE XXIV The dependence of K_{iron} (=concentration of iron in wt-%/intensity of FeK_β in counts/s) of the ash-content of human blood, in X-ray fluorescence=analysis

Ash-content, %	K_{iron}, %	$\frac{\text{Ash-content} \times K_{iron}}{100}$ Fe, %
<3	0·0029	0·000087
3·5	0·0026[5]	0·000092[5]
4·0	0·0024	0·000096
4·5	0·0022[5]	0·000101
5·0	0·0021	0·000106

The last column has been mentioned here for practical purposes: multiplication of this figure with the intensity measured on our instrument, gives the concentration of the element in % (the intensity of the FeK_β line has been measured at 1·758Å, the background at 1·815Å; excitation: 40 kV; 20 mA; vacuum).



13 *Influence of ash-content of blood ash on the K-factor of* ZnK_α



14 *Influence of ash-content of blood ash on the K-factor of* FeK_β

the scattering of the X-ray radiation and the variable depth of penetration, the larger the carbon content of the ash, the greater the depth of penetration, the more metal atoms are excited, the higher the intensity, and the lower the value of K. Tables XXIII and XXIV and Figs.13 and 14 show this effect for the elements zinc and iron.

Tables XXV and XXVI show results obtained by spectrochemical[7] and by X-ray fluorescence methods.

TABLE XXV The determination of zinc in blood spectrochemically and using X-ray fluorescence analysis

Sample No.	Ash content, %	Zn content, ppm spectrographic	X-ray fluorescence
21096	4·05	7·3	7·4
21093	4·72	8·0	7·9
21081	2·55	4·3	4·0
21079	3·13	5·0	5·1[5]
21074	4·63	5·4[5]	5·9
21065	3·92	7·0	7·2[5]
21057	4·38	7·2	7·8
21053	2·88	7·4	7·3
21037	3·01	4·2	3·9
21022	3·34	4·3[5]	4·5
21018	2·24	3·8	3·8
20212	6·25	7·7	8·1

TABLE XXVI The determination of iron in blood spectrochemically and with X-ray fluorescence analysis

Sample No.	Ash content, %	Fe content, % Spectrographic	X-ray fluorescence
20584	3·38	0·029	0·031
20578	4·85	0·045	0·042
NP 35	4·08	0·044	0·047
NP 37	3·71	0·042	0·045
NP 36	4·04	0·048[5]	0·044
20589	3·34	0·043	0·044[5]
20590	3·32	0·044	0·041
20592	3·38	0·046	0·047
20151	6·4	0·045[5]	0·042
20087	5·05	0·042[5]	0·044[5]
20188	5·7	0·042	0·042[5]

This coefficient of variation found by applying the latter method is less than 5%.

As the iron content of haemoglobin is well known (0·34%), this method may be applied in the diagnosis of anaemia.

For the X-ray fluorescence analysis of thin layers and of dilute solutions.[8]

TABLE XXVII Distribution of impurities in BCS standard steels, according to their coefficient of variation (in parentheses)

Group (*see text*)	Spectrographic methods A		B		X-ray fluorescence method	
III	Al (29)				Nb (20)	
II	Mo Cu Sn	(15)	B W Zr Sn Al	(17)	Sn Zr Cu	(6)
I	Co Cr V Ni	(9)	Cr Mo Nb V Co Ni Ti	(10)	Ni Mo V Cr Ti	(2·5)

TABLE XXVIII Some discrepancies observed between certificate values for BCS samples and results measured spectrographically and by X-ray fluorescence

British chemical standard No.	Concentration according to BCS certificate, %	Concentration according to X-ray fluorescence, %	Concentration according to spectrograph, %	Probable value, %
277	0·040 Zr	0·057	0·043–0·056	0·056 Zr
275	0·035 Ti	0·044	0·035–0·042	0·043 Ti
273	0·065 Sn	0·036	0·050–0·051	<0·05 Sn
273	0·030 Ni	0·035	0·035–0·040	0·037 Ni
273	0·045 Mo	0·039	0·039–0·039	0·039 Mo
273	0·075 Cr	0·066	0·068–0·071	0·068 Cr

CONCLUSIONS

(1) The magnitude of the standard deviation of a method of analysis for trace elements is not only determined by the method itself, but also by the degree of homogeneity of the samples in question. The larger the sample to be analysed the less the influence of inhomogeneities and *vice-versa*. In this way the coefficient of variation found spectrochemically must be greater than the one found by applying X-ray fluorescence. Spectrochemically 5 mg are examined, whereas in the X-ray fluorescence method 40–50 mg are used. (For light of a wavelength of about 1 Å half the depth of penetration into iron amounts to 0·01 mm. The surface of irradiation amounts to 17×26 mm^2. This corresponds to $0{\cdot}01 \times 17 \times 26 \times 7{\cdot}9$ mg$=35$ mg (density of iron 7·9). This effect may be seen in Table XXVII.

One could draw the conclusion that the elements of Group I divided most homogeneously, are Co, Cr, Mo, and Ni, whereas the elements in Group II (divided less homogeneously) are Sn, Zr, Al, and B. These elements do not fit in the crystal lattice of iron, they easily form oxides or carbides. And this may be the reason that they are divided less homogeneously. Uncertainty exists about the elements Ti and V (are they found accidentally in Group I?)

(2) In a few cases concentration values of some elements present in the BCS steels have been found which differ slightly from values given by the certificate. They are shown in Table XXVIII.

ACKNOWLEDGMENTS

The author's thanks are due to Miss Th. Zegeling and Mr H. J. van den Berg for their painstaking measurements.

REFERENCES

1. N. W. H. Addink *et al.*: *Applied Spectroscopy*, 1956, **10,** 128.
2. N. W. H. Addink: Colloquium Spectroscopium Internationale VI (Amsterdam 1956), *Spectrochimica Acta*, 1957, 168: J. A. M. Dickhoff, *ibid*, 162.
3. N. W. H. Addink: *ibid.*, to be published.
4. G. Sempels: *ibid.*, 1948, **3,** 346.
5. W. Seith and W. Gremm: *Mikrochimica Acta*, 1956, (*Mikrochemie-Tagung Wien*, 1955), 339.
6. A. Schleicher and L. Laurs: *Z. Anal. Chem.*, 1937, **108,** 241.
7. N. W. H. Addink: *Receuil Trav. Chim. Pays-Bas*, 1955, **74,** 197.
8. N. W. H. Addink: Colloquium Spectroscopium Internationale VII, *Rev. Univ. Min.*, 1959, 530–532.
9. N. W. H. Addink: *Spectrochimica Acta*, 1950, **4,** 36. J. A. M. Dickhoff and N. W. H. Addink: *Mikrochimica Acta*, 1955, **2–3,** 257.

Discussion

Mr **M. Milbourn** (ICI Metals Division) was in the chair.

Mr **K. M. Bills** (Mond Nickel Co. Ltd) opening the discussion said that it had been a great pleasure to hear Dr Addink's account of some of the spectroscopic methods employed in his laboratory at Eindhoven. He had been particularly intrigued by the use of the total combustion technique. Although this technique did, of course, simplify the production of standards it unfortunately resulted in unduly poor sensitivity for low-boiling-point heavy metals, and trace amounts of these elements were frequently of major metallurgical importance. He himself had found, for instance, that the shorter the exposure time the better was the similarity for the determination of lead in iron and nickel-base alloys. In fact, he endeavoured to promote the process of selective distillation by the use of globule techniques. These observations were not, of course, a point of disagreement with Dr Addink's findings since his applications were very different, but he had made them in case it was thought that the behaviour of metals in a total combustion technique was repeated in other excitation techniques.

It was very encouraging to find the simple dc arc used so effectively. He used this much-maligned source for at least half the spectroscopic estimations made in the laboratory, and it had been found that under favourable conditions a coefficient of variation of $\pm 5\%$ could be obtained at levels of 10–50 ppm.

Finally, he did not understand the measurements of relative volatility rates as expressed in terms of cm/s. One might have expected the natural measure to be mg/s. Would Dr Addink care to explain this point and describe how these volatility rates were measured?

Dr **Addink** said in reply to Mr Bills' contribution that he wished to emphasize that the sensitivity for low-boiling-point heavy metals (e.g. Pb) cannot be unduly poor, as those metals show a moderate ionization potential. He supposed that Mr Bills was most concerned by the high coefficient of variation for lead given in Table VIII. In his paper he had pointed out that the particle size of these samples was not suitable for his method of analysis, for which filings having a maximum particle size of 0·2 mm were used. The drillings varied between 1–3 mm, a size which gave rise to spluttering, and consequently low accuracy. He quite agreed with Mr Bills that it was possible to obtain better values for the coefficient of variation, and in internal reports a coefficient of variation of about 10% for low-level concentrations was generally claimed.

The second point raised by Mr Bills concerned the determination of relative volatility rates in terms of cm/s and the necessity of expressing these rates of evaporation in terms of cm/s rather than in mg/s. First the determination itself; by taking spectra at intervals of 5 s it was possible to determine the actual duration of the evaporation of a 5-mg sample. In doing so the volatility rate could be expressed in mg/s. However, in dealing with gases it was necessary to introduce the atomic weight in order to express volatility in terms of cm^3/s. To have a clearer notion of the speed of evaporation he had introduced an imaginary surface of 1 mm^2 through which the gaseous volume originating from a 5-mg sample, had to pass; details of the calculations were given in ref. 3 of the paper.

The speed of evaporation determined the loss of material thrown sideways out of the arc and it had been shown experimentally that the ratio

$$\frac{\text{speed of evaporation of the matrix}}{\text{'own speed' of element (or compound) in question}}$$

gave a good corrective factor. Fortunately, because of the large diameter of the electrodes used, this method of correction had to be carried out only in a few cases (in general when volatile elements or compounds had to be analysed).

Mr **R. C. H. MacCormac** (UKAEA) asked whether instead of using X-ray fluorescence techniques, it would have been possible to determine the zinc content of blood by chemically destroying the organic material, using, say perchloric acid and finishing off with a copper spark method.

Dr **Addink** replied that the method suggested by Mr MacCormac was perfectly feasible. Comparison of wet-chemical pre-concentration with or without dry-ashing (at even 600°C) had shown that results did not differ.* For this reason he had

* *Cf.* I. Vikbladh: Studies on zinc in blood II; 1951, Lund.

preferred the less complicated method of dry-ashing at 490°C. A dc arc method with sodium chloride as a buffer had in fact been described (*see* ref. 7 of paper). However, it had been found that the X-ray fluorescence method enabled analyses to be made with the same accuracy but at three times the speed (thirty blood samples are analysed per day for zinc and iron) and for this reason had been chosen.

Mr **Gale** (Steel Company of Wales) asked why the top electrode shown in Fig.2, A had been undercut. Normally it was the lower electrode supporting the sample which was shaped in this way in order to concentrate the heat and make volatilization of the sample more easy.

Dr **Addink** said the undercutting of the upper electrode was simply to prevent the arc wandering up the electrode during the exposure.

Mr **H. T. Shirley** (Brown-Firth Research Laboratories) asked if Dr Addink would give some indication of the method used for arc temperature measurements.

Dr **Addink** replied that the method had to be used with a spectrograph giving normal dispersion, and methods based on line broadening were therefore excluded. Consequently the well established technique of measuring the relative intensities of lines of differing excitation potentials had been employed (*see* ref. 2 of paper).

Mr **G. H. Cochett** (ARDE) asked to what extent the day-to-day variations in the intensity of each spectrum line in Table XXII were due to instability of the X-ray output and associated detecting equipment. If each spectrum line was measured with the same statistical accuracy, one would have expected that variations in the surface contours of the samples would have had the greatest effect on the longer wavelengths, i.e. Ti and CrKα, and considerably less effect on Sn and NbKα, since the sampling depth is greater for the harder radiations.

If, however, the accuracy of intensity measurement varied between the spectrum lines, were the standard deviation figures due to statistical counting errors for each of the lines given in Table XXI?

Dr **Addink** in reply said experiments (*see* p. 203, col. 1) showed that the effect of penetration depending upon wavelength was obscured by the influence of the inhomogeneity of the material (*cf.* Table XXVII).

Mr **J. H. Oldfield** (Admiralty Materials Laboratory) wrote: I am particularly interested in Dr Addink's excellent paper on trace analysis because I am at the moment concerned with the determination of sub-micro quantities of elements in semi-conductors and semi-conductor materials. I have found that working in a controlled atmosphere of a mixture of argon and oxygen not only eliminates the cyanogen bands but also increases sensitivity and assists in maintaining a steady and reproducible arc. Dr Addink has made a considerable study of the effect on sensitivity of the temperature and rate of evaporation within the arc; has he any observations to make on the use of controlled atmospheres?

Dr **Addink**: We have tried to increase sensitivity by arcing in a controlled atmosphere (argon + 10% oxygen). It resulted in an increase of the temperature of excitation by 300–400°C. We have, however, only found an improvement in the limit of detection (by a factor of about 3–5) for elements of high ionization energy such as zinc, phosphorus, and arsenic. This was only a small improvement, and we therefore discontinued the work (*see* ref. 2 of paper).

Mr **G. H. Cochett**: Could Dr Addink give reasons for the variation in the X-ray results? Are they due to the instability of the X-ray set?

Dr **Addink**: I think Table XXVII gives the answer. With regard to the Philips X-ray equipment it has been shown that over a period of three months the fluctuations are negligible. Variations shown in Table XXI (BCS Standard Sample 275) have been caused by the relatively large size of drillings of these samples, which were prepared, as far as I understand, for wet-chemical analysis.

The **Chairman** closed the discussion and thanked Dr Addink for his presentation and replies to the discussion.

The gaseous reduction of fine iron ores

S. Y. M. Ezz, Ph.D., and R. Wild, Ph.D.

SYNOPSIS

The reduction by hydrogen of fine iron-ore particles, sized between 50 and 260 μ, has been studied. The particles have been reduced while suspended as a dispersed cloud in the reducing gas. The influence on the rate of reduction of the particle size and shape, the nature of the ore and its porosity, temperature, and ore/gas ratio has been found. 1744

INTRODUCTION

AT THE PRESENT TIME considerable efforts are being made to develop the large scale production of iron by the gaseous reduction of fine particles of ore.[1–3] Such a process would be particularly attractive as the basis of a steel industry for countries which have no coking coal but large reserves of iron ore and potential sources of reducing gases. In spite of these efforts, however, relatively little fundamental work has been carried out on the behaviour of small ore particles in a stream of reducing gas[4–6] and none has been done at all using

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Dr S. Y. M. Ezz was a post-graduate student in the blast-furnace laboratory at The Imperial College of Science and Technology and is now a lecturer at Cairo University. Dr R. Wild is in charge of the blast-furnace laboratory at Imperial College.

TABLE I Iron oxide content and loss on ignition of samples at 400 and 900°C

Ore	Concentrated Rif	Sierra Leone concentrates	Cumberland	Egyptian
Mean ferric oxide content, %	95	83	60	64
Moisture content, %*	0·22	nil	0·35	0·80
Loss on ignition at 400°C, %	0·36	nil	0·87	2·30
Loss on ignition at 900°C, %	0·48	0·12	2·88	3·28

* The time for drying or ignition was always 2 h (enough to achieve constant weight).

very fine particles ($< 250\ \mu$). For this reason a detailed study has been made of the reduction of particles of this size.

A number of methods may be adopted for such a study. The material may be placed in a boat and the gas stream passed over the surface[4]; this method is unsatisfactory since only the gas has direct access to the surface layer. The gas may be passed through either static or fluidized beds of the ore particles.[5, 7] In the former case channelling may occur, particularly with very fine particles, with consequent irregularities in reduction, while in the second case sticking of the particles during reduction causes fluidization to stop. This results in poor heat and mass transfer and thus inefficient reduction. For this reason the particles used in these studies were reduced while they were suspended as a dispersed cloud in the reducing gas, a method which forms the basis of an Egyptian patent for the production of iron.[8] By the use of this technique the true behaviour of particles during reduction could be observed, without the occurrence of either channelling or sticking. Hydrogen was used for all the reduction tests to avoid the complications caused when carbonaceous gases are used.

In this work the effect of the following variables has been studied:

(i) particle size and shape
(ii) nature of the ore and its porosity
(iii) temperature
(iv) ore/gas ratio.

PREPARATION OF IRON ORE SAMPLES

The major part of the work was carried out on a dense hematite ore, Rif, but Cumberland and Egyptian (Aswan) hematites and Sierra Leone concentrates were also used so that the influence of ore structure on reduction could be studied. Rif and Cumberland ores are both hematites and owe their origin to metasomatic replacement in limestone, while the Aswan ore is an oolitic hematite of sedimentary origin. The Sierra Leone concentrates are a specular hematite of maximum density. These ores have widely different porosities, Aswan hematite being the most porous and Sierra Leone concentrates the least.

The ores were first crushed in a jaw crusher and then ground in a pan mill. It was decided to use particles having the maximum angularity for this work and thus the fine ore was frequently removed from the pan mill and screened. Sub-angular particles of Rif were prepared by prolonged grinding in a ball mill to find the effect of particle shape on reduction. Owing to the softness of the Aswan ore only sub-angular particles could be prepared. The Rif ore was screened at 100 mesh to obtain particles of a maximum size of about 200 μ. The other ores were screened at 60 mesh so that the equivalent fractions would have the same terminal falling velocities.

TABLE II Mean particle diameters, thicknesses, and volume coefficients of particles

Ore	Fraction	Particle size, μ	Particle thickness, μ	Volume coefficient (shape factor)
Angular Rif	1	154	84	0·235
	2	103	58	0·245
	3	72	40	0·235
	4	51	28·5	
Sub-angular Rif	1	167	89	0·277
	2	110	64	0·305
	3	80·5	50	0·314
	4	60·5	38	
Sierra Leone concentrates (angular)	1	206	57	0·124
	2	142	39	
	3	100	27·5	
	4	67	18·5	
Cumberland (angular)	1	192	83	0·194
	2	133	57	
	3	84	36	
	4	58	25	
Aswan* (sub-angular)	1	213	112	0·257
	2	152	80	
	3	108	57	
	4	68	36	

* Owing to the extreme softness of the Aswan ore, abrasion during cleaning and fractionation caused the sub-angularity of its particles.

The powdered ore samples were divided into four size fractions, 142–200, 100–142, 71–100, and 50–71 μ by means of an air elutriator. Smaller fractions were also collected but were not used as they tended to aggregate rather than to behave as individual particles. The gangue material in the Rif ore was mainly quartz and could largely be removed by careful screening. It was not possible to effect any concentration of the other ores used.

PROPERTIES OF IRON-ORE SAMPLES

Chemical properties

The iron oxide content and the loss on ignition at 400 and 900°C were determined and are shown in Table I. The loss on ignition at 900°C of Cumberland ore was shown to be mainly due to carbonate but that of the Egyptian ore to be mainly due to combined water which was not evolved at 400°C. The sulphur content of all the ores used was extremely small. The phosphorus content of all ores used except Aswan was also small.

Physical properties

Size and shape

The mean particle sizes and volume coefficients were determined by making microscopic determinations of the mean particle diameter d_p, the length L, breadth B, and thickness T of a number of particles. The volume coefficient K is defined by the equation,[9, 10] $V = Kd_p^3$ where V is the particle volume and d_p is determined by comparing the image of the particles with calibrated circles on an eye-piece graticule, or estimating the mean statistical intercept diameter. This is defined as the length of the line bisecting the projected area of a particle in a fixed direction for all particles.

To determine K both the flakiness ratio $m = B/T$ and the elongation ratio $n = L/B$ have to be deter-

TABLE III True and apparent density values and total, air, and hydrogen porosity

Ore	True specific gravity	Apparent specific gravity	Total porosity, %	Air porosity, %	Hydrogen porosity, %
Sierra Leone concentrates	5·12	5·12	nil	nil	nil
Rif	5·12	4·818	6·00	5·0	1·75
Cumberland	3·95	3·65	7·70	15·8	6·10
Roasted Aswan	3·83	2·64	31·00	39·5	28·0
Unroasted Aswan	3·83*	2·57	32·90	44·8	28·5

* The value of the true specific gravity for the unroasted Aswan ore is taken as that of the roasted ore.

TABLE IV Calculated values of external specific surface for all materials, and experimentally determined values for Rif ore

Ore	Particle size, d_p, μ	External specific surface, cm^2/gm calculated	experimental
Angular Rif	154	147	145
	103	215	208
	72	312	299
	51	454	492
Sub-angular Rif	167	116	114
	110	167	184
	80·5	230	249
	60·5	320	363
Sierra Leone concentrates	206	152	
	142	221	
	100	315	
	67	470	
Cumberland	192	170	
	133	245	Not determined
	84	390	
	58	564	
Egyptian	213	171	
	152	240	
	108	338	
	68	536	

mined. Then $K = Ke/m\sqrt{n}$ where Ke is a constant which has a value of 4·3 for angular particles and 5·1 for sub-angular ones.

Table II shows mean particle diameters, thicknesses, and volume coefficients of the particles. The volume coefficients were only determined for the three largest sizes of angular and sub-angular Rif particles and for the largest size fraction of the other ores.

Porosity

The pores of any particle are made up of two kinds, permeable and sealed, the former being connected to the surface of the particle and the latter not being so connected. The sum of the two, i.e. the total porosity, is normally determined by measuring the true and apparent specific gravity.[11] The true specific gravity of particles of Rif ore and Sierra Leone concentrates was taken as that of pure Fe_2O_3, i.e. 5·12 g/cm³. The values for Cumberland and Aswan ores were determined picnometrically using -10 μ particles and taking all possible precautions to ensure that the water used as picnometric fluid entered the pores of the particles. The apparent specific gravity of the Cumberland and Aswan ores and Sierra Leone concentrates was determined on larger particles (22–30 mesh) by a modified S.K. porosity apparatus.[12] Rif particles of this size could not be used as they would be mixed Fe_2O_3–quartz particles. Whereas the smaller particles used in the reduction tests were either hematite or quartz. For this material the picnometer method was employed using the largest available size of concentrated particles taking no steps to facilitate the entry of the picnometric fluid into the pores; strictly speaking this still gives a somewhat erroneous value since large open pores will be entered by the water. However, this error was subsequently found to be negligible as the permeable porosity proved to be small.

The permeable porosity was found using the S.K. apparatus, modified to enable a much smaller quantity of the powder (about 3 cm³) to be used. It was found that water could not be used in this small-scale apparatus because of errors arising from incomplete draining of the water which gave unreasonably high values for the water porosity, i.e. the pores which could be entered by water. The air porosity, i.e. the pores which could be entered by air was also found to be high, higher than the total porosity, which is quite unreasonable. Laneuville[13] had observed that the porosity as measured by air was always higher than that measured by hydrogen and he attributed this to adsorption, which took place with air and not with hydrogen. The porosity determination was thus repeated using hydrogen and much lower values were found. The behaviour of the two gases was also found to be different. The value of porosity found using air increased with time whereas a constant value was found using hydrogen and this constant hydrogen value was close to the initial value found with air. This observation is in accord with the assumption that adsorption of air is taking place but that hydrogen is not adsorbed and that the value obtained using hydrogen is the true value.

The values of true and apparent density and of total air and hydrogen porosity are shown in Table III.

External specific surface

The external specific surfaces of the particles can be calculated from the formula:

$$S = \frac{1}{\sigma} \times \frac{f}{K} \times \frac{1}{d_p}$$

where K and d_p are as defined earlier, σ=particle density, S=external specific surface, and f=surface coefficient=

$$\frac{\pi}{2} + C\left(\frac{Ke}{m}\right)^{4/3}\left(\frac{n+1}{n}\right)$$

Where Ke, m, and n are as defined earlier and C is a constant which equals 3·1 for angular particles and 2·6 for sub-angular ones.

The external specific surface of all the particles used was calculated from the above formula.

The external specific surface of the Rif ore particles was also determined experimentally by the permeability method which is based on an equation derived by Kozeny[14] and modified by Carman.[15] The apparatus used was devized by Lea and Nurse[16] for comparing the specific surfaces of materials, subsequently simplified by Rigden.[17] The apparatus was first calibrated using fine glass beads (Ballotini glass) which were closely sized and spherical.

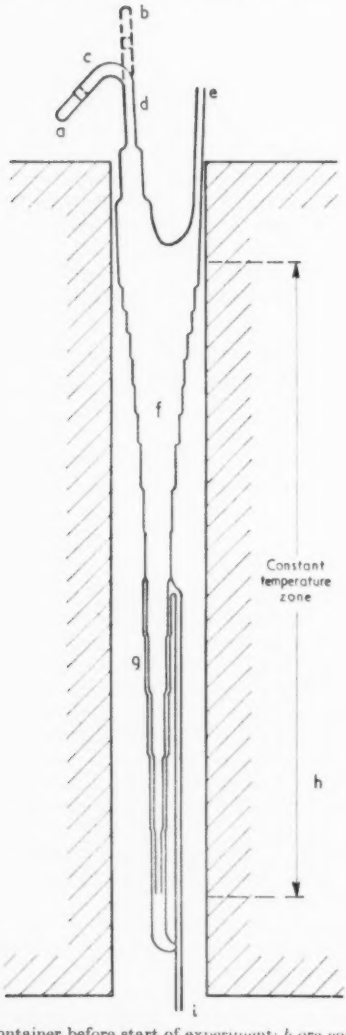
Table IV shows the calculated values of the external specific surface for all the materials, the the experimentally determined values for Rif ore.

It can be seen that the experimentally determined and calculated values of the specific surface are in good agreement except for smallest sizes. Here the particle size was outside the particle size range for which the experimental apparatus was calibrated and thus the experimentally determined values are suspect.

Internal specific surface

To obtain a measure of the permeable internal specific surface of the ores, i.e. the pore surface connected with the exterior surface, the pore volume and pore diameter would have to be known. Little is known about the latter but it can be seen microscopically that there are no pores larger than 10^{-4} cm in any of the particles and it is known that hydrogen will not enter any pore smaller than $2{\cdot}5\ \text{cm} \times 10^{-8}$. Thus, as a very rough approximation, it is assumed that the mean pore diameter is halfway between these limits, i.e. 10^{-6} cm. Using this figure and the known pore volumes as determined by the S.K. method (the hydrogen porosity) the following very approximate values for the permeable internal specific surface have been obtained.

	Sierra Leone concentrates	Rif	Cumberland	Aswan roasted	Aswan raw
Internal specific surface, cm^2/g	nil	$1{\cdot}5 \times 10^4$	$6{\cdot}7 \times 10^4$	$4{\cdot}3 \times 10^5$	$4{\cdot}5 \times 10^5$



a ore container before start of experiment; *b* ore container after start of experiment; *c* plastic tubing; *d* ore inlet tube; *e* gas exit tube; *f* reduction tube; *g* preheating jacket; *h* electric furnace; *i* hydrogen inlet tube

1 *The reduction tube*

REDUCTION OF FINE ORE PARTICLES

General principles

To measure the rate of reduction of fine iron ore particles dispersed in a cloud, two main problems must be overcome, namely:

(i) the particles must be introduced into the gas stream and kept suspended throughout the test
(ii) the rapid rate of removal of oxygen must be measured.

The first of these problems was overcome by dropping the sample into a conical reaction tube up which hydrogen is passed. This tube was so constructed that any sized sample would remain suspended in the gas stream at some level within its length.

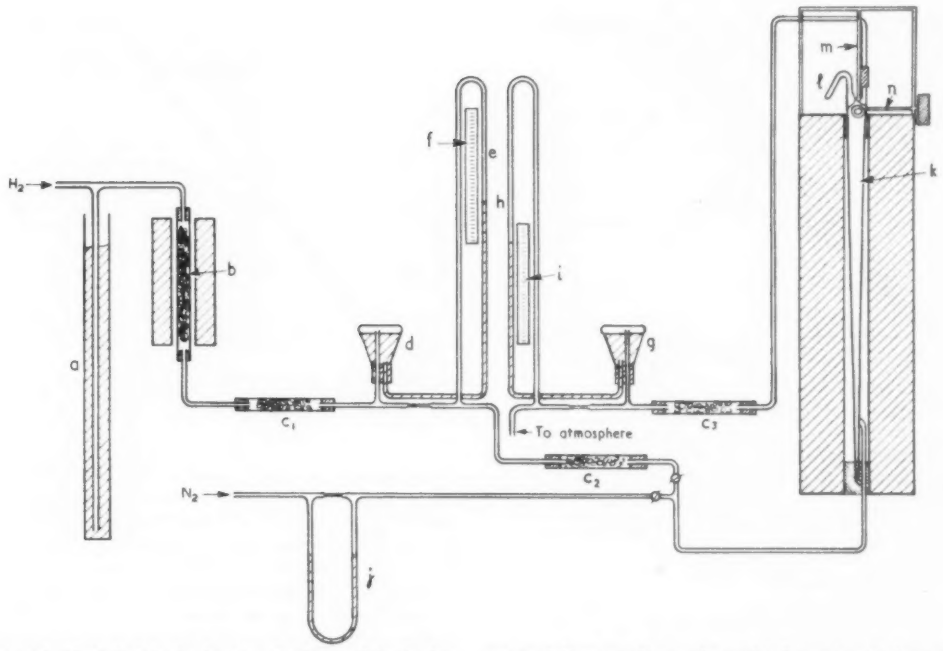
The second proved to be more difficult to solve. The normal method of following reduction by hydrogen is to weigh the water produced during the reaction. Initially an attempt was made to use a modification of this method to follow the reduction. An eight-way electrically heated brass stopcock was constructed so that the exit gases could be led through one of a number of absorption tubes in turn without interrupting the hydrogen flow in the process. While this method proved suitable for measuring the relatively slow reduction rates encountered at low temperatures, it was unsuitable for use at higher temperatures. The reason for this was that, because of its somewhat clumsy nature, it took from 1 to 2 s to move the key from one position to another and this time was quite long compared with the total time of reaction.

Methods depending on automatic recording using either the infra-red or conductivity principle or on automatic weighing of the water evolved were considered but were rejected, in the first case because of the lag in response and in the second because of practical difficulties.

The method finally used depended on the difference of hydrogen flow into and out of the tube, the water formed being absorbed before the second flowmeter.

Apparatus

The reduction tube (Fig.1) was designed so that the smallest particles which would be used (about 40 μ) would not, after reduction, be blown out of the tube at the highest temperature (1000°C) while the largest unreduced particles (about 250 μ) would not fall out of the tube at the lowest temperature (500°C). Preliminary work had been carried out on the terminal falling velocities of particles in both air and hydrogen at varying temperatures and equations had been established[18] which enabled the limiting terminal falling velocities to be calculated; these were 5·5 and 382 cm/s. A flow rate of 500 cm^3/min (at room temperature) was chosen as convenient and thus the maximum (top) and minimum (bottom) diameters of the reaction tube should be 2·94 and 0·275 cm respectively. The top and bottom diameters were 3·3 and 0·20 cm. The whole tube (*f*, Fig.1) was constructed by joining fifteen pieces of silica tube together whose lengths varied from $7\frac{1}{2}$ cm at the bottom to $2\frac{1}{2}$ cm at the top. This variation in length was to even out somewhat the volume available for each size fraction of particles. A jacket *g* was fixed round the lower part of the reaction tube, the annular width of which was about 1 mm. The gas entered the top of this jacket and was preheated as it passed down. The extended bottom of the preheating



a constant head; *b* platinized asbestos tube for purifying hydrogen; *c* drying tubes; *d* reservoir of inlet flowmeter; *e* measuring limb of inlet flowmeter; *f* direct reading scale, inlet flowmeter; *g* reservoir of outlet flowmeter; *h* measuring limb of outlet flowmeter; *i* direct reading scale, outlet flowmeter; *j* nitrogen flowmeter; *k* reduction tube; *l* glass cup for containing ore; *m* reduction tube suspension; *n* electrically operated hammer for striking tube

2 *Layout of apparatus for reduction tests*

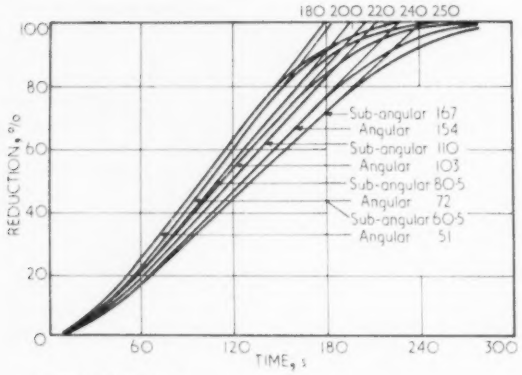
tube was joined to the gas inlet tube *i* to increase the stability of the apparatus. To the top of the reaction tube were joined an inlet tube for the ore *d* and an outlet tube for the gas *e*. A small glass cup *a* could be joined to the top of the inlet tube by transparent plastic tubing *c*. The reaction tube was suspended in an electric tube furnace *h* which had been constructed in such a manner that it had a constant temperature zone 2 ft long so that the critical section of the reaction tube was at the desired temperature (to within $\pm 2°C$). This temperature was measured by five chromel–alumel thermocouples evenly distributed over the 2-ft zone. To minimize the possibility of material sticking to the walls the reaction tube was struck three times per second by an electrically operated hammer (*n*, Fig.2).

The general layout of the apparatus is shown in Fig.2. Hydrogen was supplied and maintained at a constant pressure by a constant head device *a*. It was purified by passing it through heated platinized asbestos *b*, dried c_1, passed through the inlet flowmeter, redried c_2 and passed into the reduction tube *k*. On leaving the reduction tube the water was removed by the drying tube c_3 and then the gas passed out through the outlet flowmeter. Nitrogen, for sweeping out the apparatus, could be supplied via a flowmeter *j*. The inlet flowmeter consisted of a reservoir *d* and a vertical limb *e*, the outlet flowmeter was of identical design (reservoir *g*, vertical limb *h*). The flowmeters were arranged so that their vertical limbs were side by side.

Since the reduction rate is very fast it was essential that the response of the flowmeters to changes in flow should be very rapid. To minimize any lag in response a small quantity of aerosol was added to the water used as flowmeter liquid and the flowmeter limbs were treated with silicone oil in such a manner that the inside surfaces were covered with a very thin layer of silicone. These measures diminished the surface tension of the water and prevented cohesion between it and the glass. Besides the normal linear scales the flowmeters were provided with additional scales (*f* and *i*) from which it was possible to read directly the volume of hydrogen consumed in various units of time. Since the reaction was very rapid, particularly at the higher temperatures, the time and the flowmeter movements were recorded by exposing a few frames of ciné film at suitable intervals.

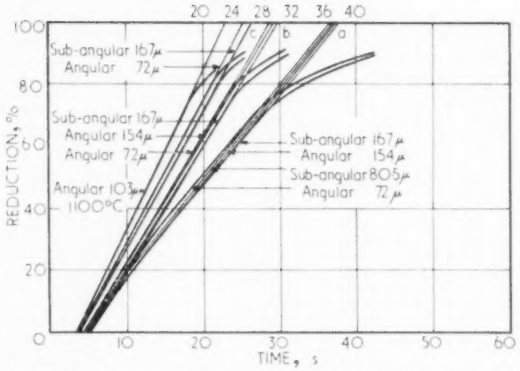
Experimental procedure

The desired quantity of ore (normally 0·2 g) was weighed into the glass cup. This was then joined to the ore inlet tube by plastic tubing, which was fixed in such a position that the solid remained in the cup (*see a*, Fig.1). The hydrogen, which had been flowing for some time to ensure that any reoxidized iron particles from the previous experiment adhering to the tube would be completely reduced, was adjusted so that a flow of 500 cm^3/min was passing and the furnace temperature throughout the constant temperature zone was checked. The H_2 was allowed to flow through the tube for 15 min after the cup had been placed in position so that it could replace the air. The clock and the experiment number were placed in position, the electric hammer started, and the experiment began with the release of the cup so that the plastic tubing straightened causing the ore to fall into the tube (Fig.1). Readings were taken by operating the ciné camera at intervals varying from 2 to 20 s depending



Dimensions are in μ

3 *Rate of reduction of Rif ore at 500°C*



5 *Rate of reduction of Rif ore at* (a) *800°C*, (b) *900°C*, (c) *1000 and 1100°C*

on the reaction rate. When the flowmeters returned to their original position, indicating that reaction was over, the cup and plastic tube were removed and a high nitrogen flow was passed up through the apparatus to blow the solid out through the top. While flushing with nitrogen the tube was vigorously struck with the tapping mechanism and the inside walls rubbed with a nichrome wire to remove adhering particles.

When the ore sample was dropped into the reaction tube there were considerable fluctuations of the flowmeters due to the initial cooling of the system by the particles, which caused a drop in pressure inside the tube, and the subsequent heating of the excess gas drawn in. These fluctuations lasted for 1 or 2 s only, after which the flowmeters settled down and moved steadily, the hydrogen flow into the reaction tube first increasing and then decreasing to about the initial value and the hydrogen flow-out varying in the reverse manner. These changes were caused by the drop in pressure between the flowmeters which was the result of the consumption of hydrogen and the absorption of the water formed.

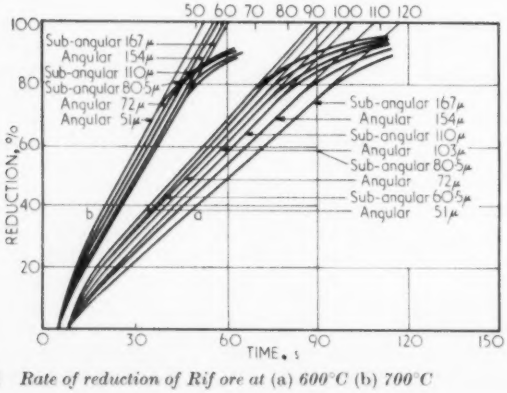
The recorded results show directly the volume of hydrogen consumed in each unit of time and a summation of these gives the total volume of hydrogen consumed. This should agree with the value calculated from the iron oxide content of the ore; normally it is very close but sometimes it varies by as much as $\pm 5\%$. Changes in atmospheric pressure and temperature, incomplete response of flowmeters to changes in flow and the loss of ore, caused by abrasion during its introduction into the tube, all introduce errors. These errors are minimized, however, if the total volume of hydrogen consumed is based on the flowmeter readings rather than on the total weight of oxygen in the ore. From the flowmeter readings the percentage reduction in any unit of time and the cumulative percentage reduction can be calculated and a plot of the latter against time gives a rate of reduction curve.

DISCUSSION OF RESULTS

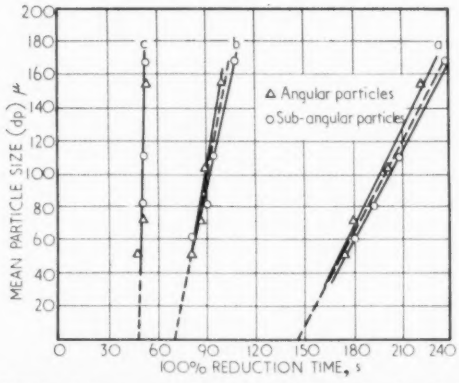
General course of reduction

A number of features are common to all the rate of reduction curves, namely (*a*) an apparent time lag before reduction starts, (*b*) an initial portion in which the nature of the curves varies considerably, (*c*) a straight-line portion which normally covers more than 50% of the total reduction, and (*d*) a final slowing down of the reduction rate.

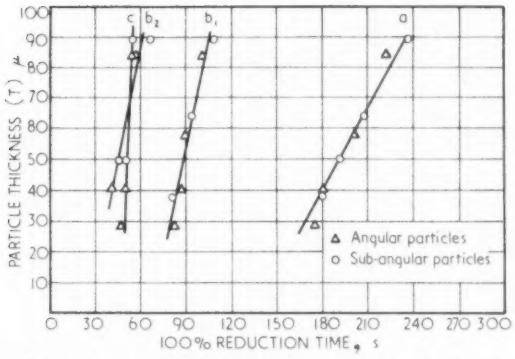
The time lag at the start represents the time taken for the water vapour to travel from the reaction tube to the dehydrating tube. In the second period the rate is influenced by the surface condition of the particles and by the auto-catalytic nature of the initial reaction. In the final stage the small quantity of available oxygen and the time taken to remove the last traces of water from the system cause a bending of the reduction-rate curve. The straight-line relationship shows that the reduction is a zero order reaction. While this



4 *Rate of reduction of Rif ore at* (a) *600°C* (b) *700°C*



6 *Relation between particle size and 100% reduction time for Rif particles at* (a) *500°C*, (b) *600°C*, (c) *700C°*



7 *Relation between particle thickness and 100% reduction time for Rif particles at* (a) *500°C*, (b) *600°C*, (c) *700°C* (b_2) *for zero ore concentration at 600°C*

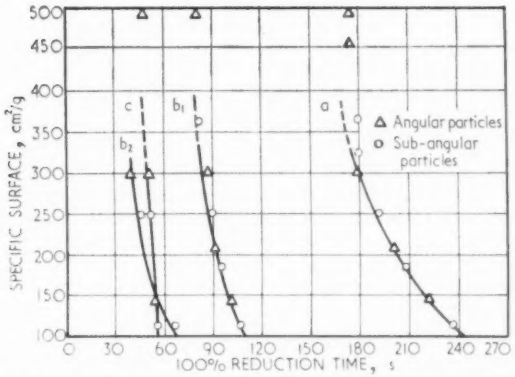
is not an unusual phenomenon it has not previously been reported for iron-ore reduction. All previous workers have found that the reduction rate decreases with time. However, all previous workers used much larger particles where the effect of diffusion into and out of the particles was much greater and where the time of reduction was much greater, and thus there was a greater probability of changes occurring in the chemical composition and physical structure of the ore which would slow-up reduction. This straight-line relationship is caused by a number of factors[18] of which the following are clearly of importance:

(i) large surface-to-volume ratio of the small particles

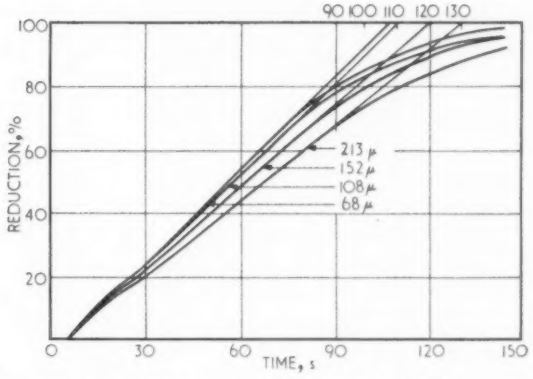
(ii) short time of reaction which lessens the chance of changes in the composition and structure of the ore taking place which would slow up reaction

(iii) porosity of the particles and the development of cracks and fissures which will increase the available surface.

The actual conclusion of reaction is difficult to determine precisely and thus for the determination of the reducibility index the straight-line portion of the curve has been extrapolated to 100% reduction, and the difference between the time at which this extrapolated line cuts the 100% reduction axis and the time



8 *Relation between specific surface and 100% reduction time for Rif particles at* (a) *500°C*, (b_1) *600°C*, (c) *700°C*, (b_2) *for zero ore concentration at 600°C*



9 *Rate of reduction of unroasted Aswan ore at 600°C*

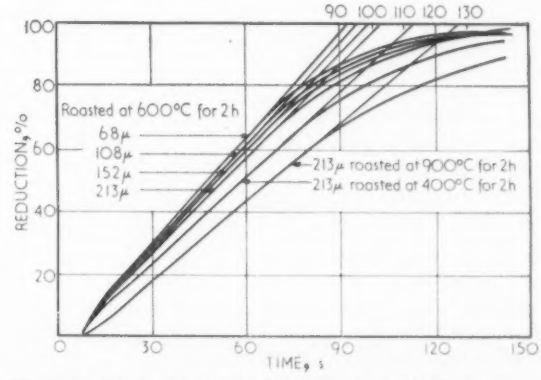
at which reduction started is called the '100% reduction time' and used as an index of reducibility. This value is, to all intents and purposes, a measure of the slope of the straight-line portion of the graph, which is proportional to the reaction rate over the major portion of the reaction period.

Effect of particle size, thickness, and external specific surface

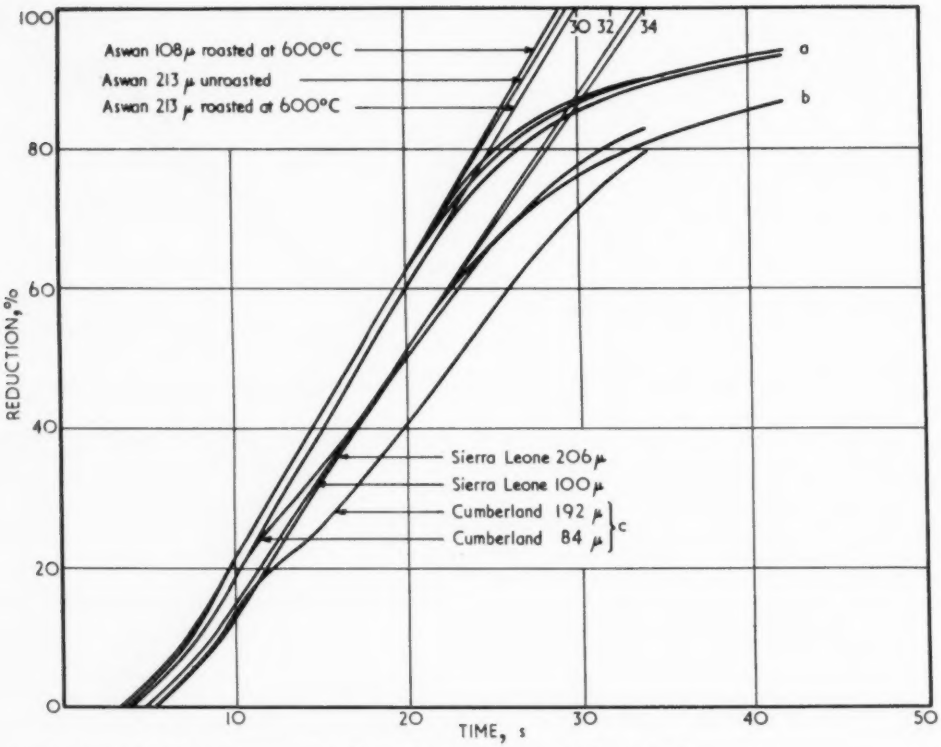
Figures 3–5 show the reduction rate using different particle sizes while Figs.6–8 show the relation between the 100% reduction time and particle size, thickness, and external specific surface. From these curves it can be seen that the influence of these characteristics on 100% reduction time is less than would be expected and that it decreases with increasing temperature.

Neglecting the influence of porosity, the characteristics which can most affect reduction are particle thickness and specific surface. Theoretically one would expect that doubling the particle thickness would double the time for reduction but this is certainly not the case; for example, at 500°C the time for 100% reduction is only increased by about 20% when the thickness is doubled and at 800°C there is virtually no difference at all. Similarly one might expect the reduction rate to be directly proportional to the specific surface for fine material but in fact specific surface has a much smaller effect.

At lower temperatures there is an appreciable difference between the reduction rate of angular and sub-angular particles of the same size, the angular



10 *Rate of reduction of roasted Aswan ore at 600°C*



11 *Rate of reduction at 900°C* (a) *Aswan ore* (b) *Sierra Leone concentrates* (c) *Cumberland ore*

being more rapidly reduced. This is to be expected since angular particles have a larger external specific surface than sub-angular. All points for both angular and sub-angular particles lie on the same line for all temperatures when 100% reduction time is plotted against external specific surface (Fig.8).

The factors which mask the influence of particle size and shape upon reduction rate may be summarized as follows:

(i) porosity of the particles which helps to expose the inner particle surface to the reducing gas
(ii) cracking and fissuring of particles during reduction
(iii) concentration of water vapour around the particles which increases the time of reduction and thus decreases the relative differences in 100% reduction time. In connection with (iii), experiments were carried out in which the ore/gas ratio, and hence the water concentration in the reducing gas, was varied. These experiments, which will be described later, enabled the 100% reduction time for zero particle concentration to be obtained by extrapolation. If the effects of specific surface and thickness are plotted for zero particle concentration it can be seen that the effect of particle size and shape is proportionately greater (curves B2, Figs.7 and 8).

Similarly the factors which will cause the influence of particle size and shape to diminish with increasing temperature may be summarized as follows:

(i) increase in diffusion rate with increasing temperature which makes it easier for gases to enter and leave a particle
(ii) increasing tendency for cracking with increased temperature
(iii) increase of water vapour concentration with temperature, due to increased reaction rate.

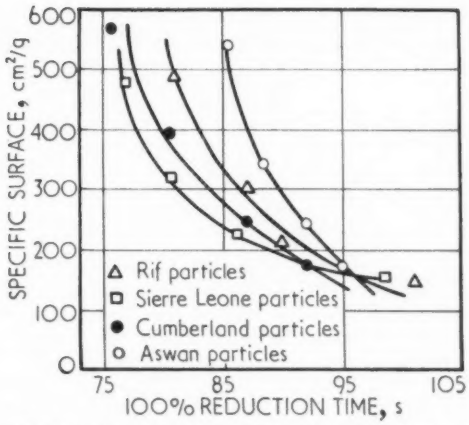
Effect of nature of ore

Aswan ore contained an appreciable quantity of combined water which was not completely removed by roasting unless this was carried out at not less than 600°C. The time for 100% reduction of 213-μ Aswan ore particles roasted at various temperatures (Figs.9 and 10) is shown below:

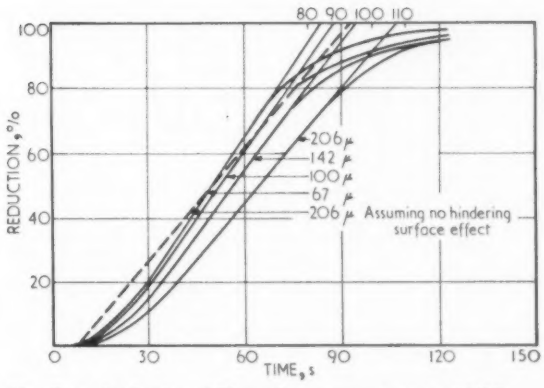
	Roasting temperature, °C			
	Unroasted	400	600	900
100% reduction time at 600°C, s	125	107	95	121

It is clear that the reduction rate was a maximum for particles roasted at 600°C. With unroasted particles or particles roasted at a lower temperature water was evolved within the particles during reduction which increased the water concentration at the seat of reaction. It would appear that roasting at 900°C brought about physical changes within the ore which diminish its reducibility, probably by lowering its porosity.

When reduction was carried out at 900°C there was no difference in the behaviour of Rif and roasted or unroasted Aswan ore (Figs.5 and 11), presumably because the water was removed very rapidly before reduction started, and as previously noted, the



12 *Relation between specific surface and 100% reduction time at 600°C of the different ores*



13 *Rate of reduction of Sierra Leone concentrates at 600°C*

physical characteristics of the ores had very little effect on reduction rate at higher temperatures.

At 900°C Cumberland ore behaved anomalously in that there was an appreciable retardation of the reaction rate at around 25% reduction (Fig.11). This may be due to the production of water at the particle surface at this stage of the reduction. The ore contained $CaCO_3$ which will decompose at this temperature. The CO_2 evolved will react with H_2 to form H_2O and CO only when metallic iron has been formed to catalyse the reaction. This effect was more serious in the larger particles, where the carbonate was present in the same particles as the iron oxide, than in the small particles which were either pure oxide or carbonate. No attempt has been made to give 100% reduction figures for Cumberland ore since the water gas reaction produced CO which rendered the readings of the 'out' flowmeter inaccurate. It is, however, reasonable to assume that if $CaCO_3$ had not been present the reaction rate would have been the same as that of Rif and Aswan ores.

Influence of porosity

The effect of porosity could not be studied independently from that of the particle's shape factor. It was possible, however, to determine the relative importance of these two factors. In Fig.12 the 100% reduction time is plotted against specific surface for particles of four ores, with different shape factors and different porosities. It can be seen that, for all except the largest particles, the reducibility lies in the order Sierra Leone concentrates>Cumberland>Rif>Aswan. This is also the order of increasing shape factor (*see* Table II), i.e. decreasing angularity. On the other hand, the particles of ore with the highest porosity are the least reducible while the ore particles with lowest porosity are the most reducible. Thus it is clear that, for the smaller particles, the shape factor has the greater influence on reducibility.

Figure 12 also shows that external specific surface has a lesser influence on reducibility when the porosity of the particles is large. This is because the larger particles of the porous ore will be more easily penetrated by reducing gas.

Influence of surface condition

At the lowest temperature used (500°C) there was an appreciable time lag before reduction started, followed by a gradual increase in the reaction rate until the constant value was reached (Fig.3). This behaviour is typical of an auto-catalytic reaction and it is also normal for this effect to be most marked at low temperatures. With all ores, except Sierra Leone concentrates, the course of reduction was different at 600°C, the slow start of the reaction having disappeared (compare Fig.13 with Figs.4, 9, and 10). Reaction starts at surface imperfections (active centres) and the extent of the initial delay in reaction must be associated with the degree of surface roughness. The Sierra Leone particles were very smooth and lacked surface imperfections of any kind and thus the inception of reduction was more difficult.

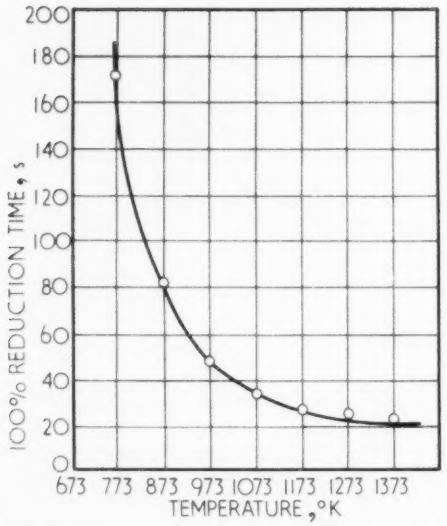
Effect of temperature

The relationship between the 100% reduction time and the absolute temperature, for Rif ore particles, is shown in Fig.14. At lower temperatures where particle size influences the reduction rate the 100% reduction time for the smallest particle size was used.

Since the reaction, over the major part of its duration, is zero order the plot of log (% reduction/time) against the reciprocal of the absolute temperature should give a straight line from which the activation energy may be calculated.

Figure 15 shows this relationship for three sizes of ore particles and it is clear that at temperatures below 1000°C this is true, though there is a tendency for the 500°C value to lie slightly off the line. From Fig.15 the activation energies may be calculated. They are 7·9, 8·8, and 9·5 kcal for the 51 μ, 110 μ, and 167 μ particles respectively. This increase in the value of the activation energy is associated with the decreasing surface area to volume ratio.

The reduction rates at 1000° and 1100°C are both suspect because the particles had a tendency to stick to the walls and so remain in a region of low gas velocity. A single value of the reduction rate at 400°C had been found for the largest sized particles using the brass key method. This value has been inserted in Fig.15 and it can be seen to be appreciably off the straight line. This is not surprising since the mechanism of reduction is different at temperatures above and below the quadruple point temperature, 565°C. It may be noted that the line joining the points corresponding to 400° and 500°C when extended intersects the line



14 *Relation between temperature and 100% reduction time for 0·2 g of Rif particles*

joining the high temperature points at a point corresponding to about 530°C, reasonably close to the quadruple temperature.

Effect of ore/gas ratio

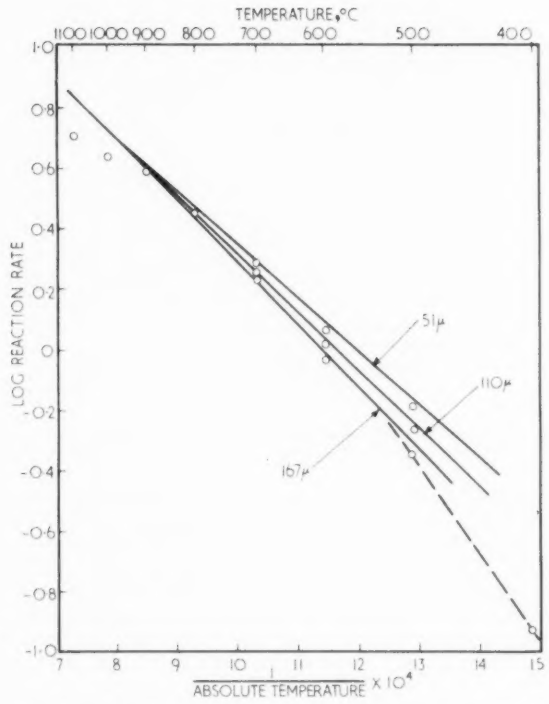
The effect of this was studied at 600° and 900°C, the following experiments being carried out:

Temp., °C	Ore weight, g				
600	0·05	0·10	0·20	0·40	0·80
900	0·025	0·05	0·10	0·20	0·40

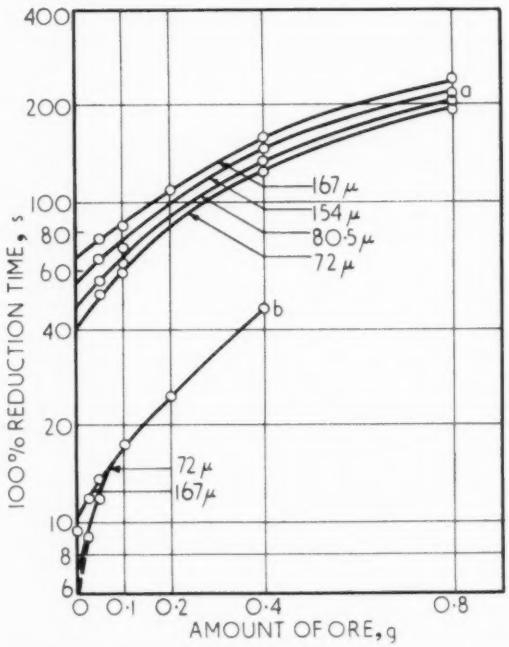
The reduction-rate curves were plotted in the normal manner and from them the 100% reduction times were obtained. These are shown plotted, in Fig.16, against ore weight on a log-arithmetic scale, so that, by extrapolation, the 100% reduction time for zero particle concentration could be found. It is clear that the influence of particle size is more marked at lower temperatures and at lower ore/gas ratios. High temperature and high ore/gas ratios will increase water concentration and so tend to mask the effect of particle characteristics. The major influence on reduction rate will be exerted either by the chemical reaction rate or by gaseous diffusion depending on which is the slowest process. When water concentration in the gas is high, the chemical reaction rate will be slow and largely control the rate of reduction. When it is low, on the other hand, the chemical reaction rate will be high and diffusion, which is influenced by particle and ore characteristics, will tend to be the controlling factor.

At high temperatures and high ore/gas ratios, where the reaction is mainly controlled by the chemical reaction rate, the weight of water formed in unit time will tend towards a constant value. When this happens the reduction rate and the 100% reduction time will be directly proportional to the weight of ore used. This trend may be seen from the following figures. At 600°C doubling the ore weight from 0·1 to 0·2 g increases the 100% reduction time by a factor of 1·4, whereas a change from 0·4 to 0·8 increases this factor to 1·6; at 900°C for a change from 0·2 to 0·4 g the factor is 1·9.

At temperatures above 600°C particle and ore



15 *Relation between the log reaction rate and the reciprocal of absolute temperature for the three sizes of Rif particles*



16 *Relation between amount of ore and 100% reduction time for Rif particles at* (a) *600°C*, (b) *900°C*

TABLE V Fe–FeO, H_2–H_2O equilibrium data and time for 100% reduction

Temp., °K	RT ×2·303	Ore weight, g	K'	K	log K'	log K	log K'– log K	$\Delta_M F = -2{\cdot}303\ RT(\log K' - \log K)$ cal/mol	100% red. time, s
873	3997	0·1	0·0405		−1·393		−0·9164	3660	61
		0·2	0·0607	0·334	−1·217	−0·4786	−0·7404	2960	83
		0·4	0·0805		−1·095		−0·6184	2470	127
		0·8	0·1045		−0·981		−0·5044	2020	200
973	4456	0·2	0·1123	0·420	−0·950	−0·3771	−0·5729	2556	47
1073	4920	0·2	0·1680	0·502	−0·775	−0·2995	−0·4755	2340	33
1173	5370	0·1	0·152		−0·819		−0·5936	3190	18
		0·2	0·2305	0·595	−0·638	−0·2254	−0·4126	2218	25
		0·4	0·2520		−0·599		−0·3736	2005	47

characteristics have very little influence on the rate of reduction. The only factors which have an appreciable influence are temperature and ore/gas ratio and it is possible to derive a single expression linking these.[18]

Effect of gaseous diffusion and free energy of reaction on reduction

The driving force can be calculated from the following equation:

$$\Delta F = RT\,(\ln K' - \ln K)$$

where R=gas constant, T=absolute temperature, $K' = [H_2O]/[H_2]$ during reaction, $K = [H_2O]/[H_2]$ at equilibrium.

The mean value of K' can be calculated from a knowledge of the oxygen removed from the ore and the hydrogen passed during its removal. K can be determined from the known Fe–FeO, H_2–H_2O equilibrium data and so $-\Delta F$ can be calculated. Table V shows the data and also the time for 100% reduction. At a constant temperature with varying ore weight the reduction time increases as $-\Delta F$ decreases as would be expected, but at a constant ore weight $-\Delta F$ decreases as the 100% reduction time decreases with increasing temperature. While $-\Delta F$ is proportional to temperature, gaseous diffusion is proportional to $T^{1{\cdot}8}$, i.e. diffusion rate increases more rapidly than $-\Delta F$ with increasing temperature. Thus reduction rate increases more rapidly than it would if it were governed solely by the value of $-\Delta F$. This results in an increase in the water concentration in the gas and, in consequence, a decrease in the value of $-\Delta F$.

CONCLUSIONS

From this work the following general conclusions may be drawn:

(1) There is a linear relationship between percentage reduction and time over the greater part of the reduction period indicating a zero order reaction. The large surface/volume ratio of the particles, their porosity, the exposure of additional surface by cracking and fissuring, and the small chance of physical changes occurring during reaction all contribute to this relationship.

(2) The particle characteristics, size, thickness, and specific surface, have only a relatively small effect on the reduction rate. The effect of these variables decreases, and eventually becomes negligible, as the temperature and the ore/gas ratio increases.

(3) The reducibility of ores containing either combined water or carbonate is markedly decreased at temperatures at which evolution of H_2O or CO_2 takes place. While ore characteristics such as porosity, shape factor, and surface condition have relatively little influence on reduction rate, the shape factor has the larger influence with small-sized particles but porosity becomes increasingly important as particle size increases.

(4) Temperature exerts a major influence on reduction rate, increasing temperature giving increasing reduction rate. The relation between time for 100% reduction and temperature appears to be different above and below the quadruple point due to the difference in the chemical reactions taking place.

(5) The concentration of water in the reducing gas which, in these experiments, depends on the ore/gas ratio, has a major influence on the reduction rate. The time for 100% reduction increases as this ratio increases, finally tending towards a direct proportionality between ore weight and reduction time.

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REFERENCES

1. A. M. Squires and C. A. Johnson: *J. Met.*, 1957, **9**, 586–590.
2. A. Hegarty: *Iron and Steel*, 1957, **30**, 483–485.
3. H. W. McQuaid: *Iron Steel Eng.*, 1958, 69–78.
4. O. Specht and C. Zapffe: *Trans. AIME*, 1946, **167**, 237–277.
5. M. Udy and C. Lorig: *ibid.*, 1943, **154**, 162–181.
6. J. Edstrom: *JISI*, 1953, (III), 289–304.
7. W. Wetherill and C. Furnas: *Ind. and Eng. Chem.*, 1934, **26**, 983–991.
8. S. Y. M. Ezz: 'The shower furnace', Egyptian patent no.1, 1954.
9. H. Heywood: Symposium on particle size analysis, Supp. to *Trans. Inst. Chem. Eng.*, 1947, **25**, 14–24.
10. H. Heywood: Symposium on Mineral Dressing, *Inst. Min. Met.*, 1952, 31–58.
11. T. Joseph: *Trans. AIME*, 1936, **120**, 72–98.
12. H. L. Saunders and H. J. Tress: *JISI*, 1945, (II), 291p–302p.
13. J. Laneuville: 'Porosity and adsorptivity of iron ores from New Quebec', Dept. of Mines, Quebec Prov., Canada, 1953.
14. J. Kozeny: *Ber. Wien. Akad.*, 1927, **136a**, 271.
15. P. Carman: *Trans. Inst. Chem. Eng.*, 1937, **15**, 150–166.
16. F. Lea and R. Nurse: *Trans. J. Soc. Chem. Ind.*, 1939, **58**, 277–283.
17. P. Rigden: *ibid.*, 1943, **62**, 1–4.
18. S. Y. M. Ezz, Ph.D thesis, London University, 1958.

Liquidus–solidus relations in the system iron–aluminium

J. R. Lee

SYNOPSIS

The liquidus and solidus curves for the system iron–aluminium have been determined accurately by thermal analysis. The addition of aluminium to iron produces a very slight rise in the freezing point but it is not possible to say whether this is a characteristic of the true binary equilibrium diagram or whether it is due to the removal of the last traces of oxygen from the high-purity iron which was used for the experiments. The system contains two eutectics in the region 65–75 at-%Al, and the previously accepted diagram is shown to be incorrect in indicating a peritectic horizontal. 1793

INTRODUCTION

PREVIOUS WORK on the equilibrium diagram of the system iron–aluminium has been reviewed by Hansen.[1] The work of several investigators was in agreement as to the general form of the liquidus curve, except in the region 65–80 at-%Al, where Gwyer and Phillips[2] found two eutectic points, whilst Ageew and Vher[3] claimed to establish the existence of one eutectic, and one peritectic horizontal. The solidus curves for the equilibrium diagram have not previously been determined accurately, and are shown by dotted lines in Hansen's diagram. In these circumstances a redetermination of the liquidus and solidus curves has been made for the whole range of composition.

EXPERIMENTAL

The alloys were prepared from *H* iron, kindly presented by the British Iron and Steel Research Association; the purity of this was comparable with that used by Hellawell and Hume-Rothery.[4] The aluminium was obtained from the British Aluminium Co. Ltd, and was of 99·99% purity.

Thermal analyses were carried out using the experimental methods described by Hellawell and Hume-Rothery[4] to whose paper reference should be made for details. Refractories of pure alumina were used, and the alloys were melted in an atmosphere of argon, after thorough degassing of the furnace to a pressure of less than 10^{-4} mmHg up to 600°C. Ingots of about 5 cm^3 were used, and all the precautions previously described were taken to obtain accurate results. After a cooling curve had been taken, the ingot was held for at least one hour at a temperature within 50°C of the expected solidus point, after which a heating curve was taken.

In the range 0–80 at-%Al, it is thought that the liquidus points are reproducible to within $\pm$ 1·0°C. The solidus points in the range 0–75 at-%Al should be accurate to within $\pm$ 1·5°C.

After each experiment, the ingot was weighed, and the result compared with that of the weights of metals used. The loss in weight was so slight that it was thought justifiable to base the results on the synthetic compositions. Experience with a wide range of alloys suggests that, in systems where contamination and volatilization can be prevented, this method is as accurate as that based on chemical analysis, particularly when a microscopical examination of the ingot is desirable. With polyphase alloys, perfect uniformity of composition throughout the final ingot cannot be ensured, and the loss of material during the preparation of the microsection may mean that a chemical analysis of the remaining specimen does not give the composition of the ingot as a whole. A representative batch of alloys was subsequently analysed, and the results closely confirmed the synthetic composition.

All furnace-cooled ingots were examined microscopically. Annealing and quenching experiments were carried out in an atmosphere of pure helium; the specimens were contained in iron crucibles as described elsewhere.[5]

EXPERIMENTAL RESULTS

The results for the liquidus points are given in Table I, and are plotted in Figs.1 and 2.

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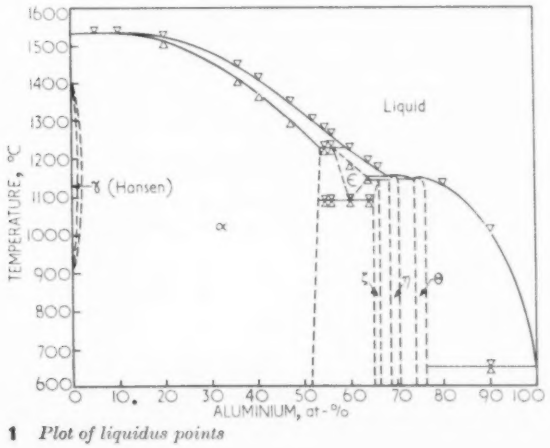
Mr Lee was formerly at the Department of Metallurgy, University of Oxford.

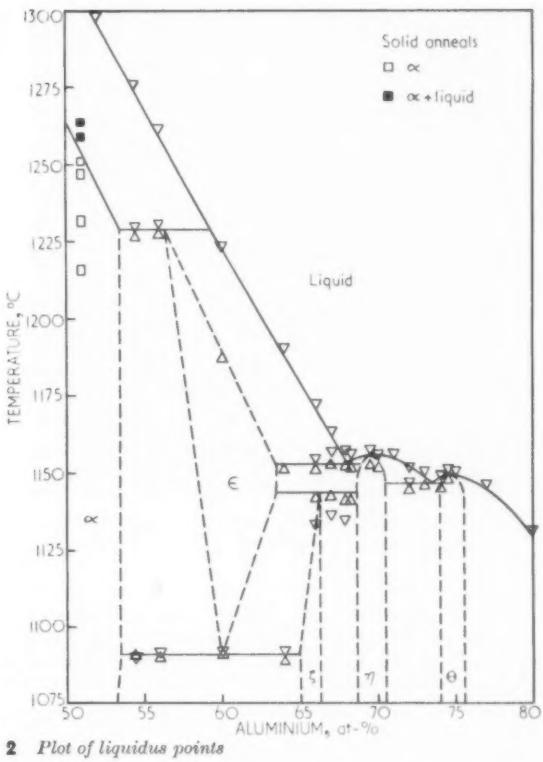
TABLE I Liquidus points

Alloy, at-%Al	Arrest points	Cooling, °C	Heating, °C
5	Liquidus	1534·7	
10	Liquidus	1536	
20	Liquidus	1522	
	Solidus		1515·8
36	Liquidus	1443·5	
	Solidus		1410
40·5	Liquidus	1407·5	
	Solidus		1369
47·2	Liquidus	1344·3	
	Solidus		1298·5
52	Liquidus	1296	
54·4	Liquidus	1274·3	
	Peritectic	1228·5	1228·5
	Eutectoid	1088·5	1093
56	Liquidus	1260	
	Peritectic	1229	1229
	Eutectoid	1090	
60	Liquidus	1221·5	
	Solidus		1188·9
	Eutectoid	1090·4	1093
64	Liquidus	1189	
	Eutectic		1153
	Eutectoid	1090·4	1091
66	Liquidus	1170·5	
	Eutectic	1152·8	1152·8
	Peritectoid	1131·5	1143·7
67	Liquidus	1161·5	
	Eutectic	1155	1154
	Peritectoid	1134·6	1144
67·9	Liquidus	1155·5	
	Eutectic		1154
	Peritectoi	1133	1143
68·25	Liquidus	1154·3	
	Eutectic		1153·5
	Peritectoid		1143·3
69·5	Liquidus	1155·7	
	Solidus		1154·7
70	Liquidus	1154·3	
	Solidus		1153·5
71	Liquidus	1154·3	
	Eutectic		1148
72	Liquidus	1150	
	Eutectic	1145·4	1146·5
73	Liquidus	1149	
	Eutectic		1147·6
74	Liquidus	1147·6	
	Eutectic		1146·9
74·6	Liquidus	1149·8	
	Solidus		1149·8
75	Liquidus	1149	
77	Liquidus	1144·5	
80	Liquidus	1129·8	
90	Liquidus	1006·8	
	Eutectic	652	652

The addition of aluminium to the *H* iron produces a very slight rise in the liquidus and solidus curves, which reach a maximum at 1536°C and about 10 at-%Al. It is not possible to say whether this is a real characteristic of pure Fe–Al alloys, or is due to the

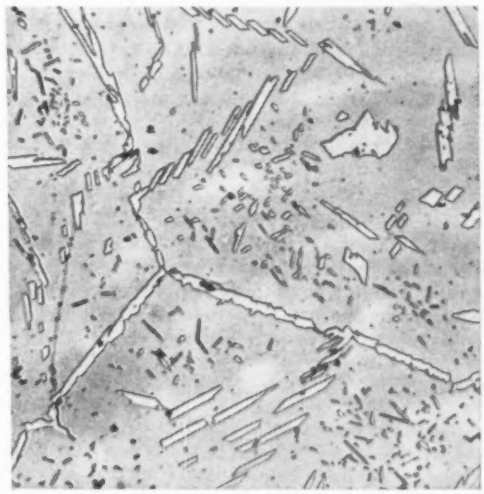


1 *Plot of liquidus points*

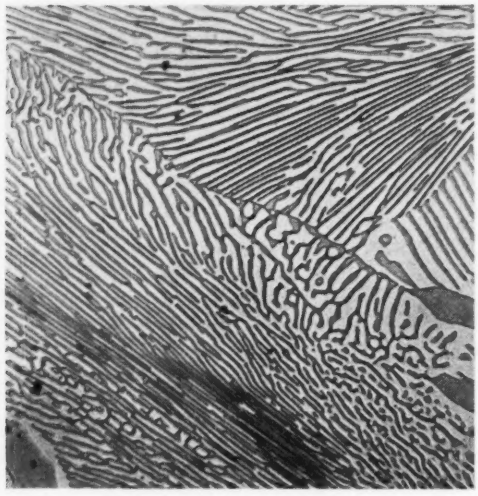


2 *Plot of liquidus points*

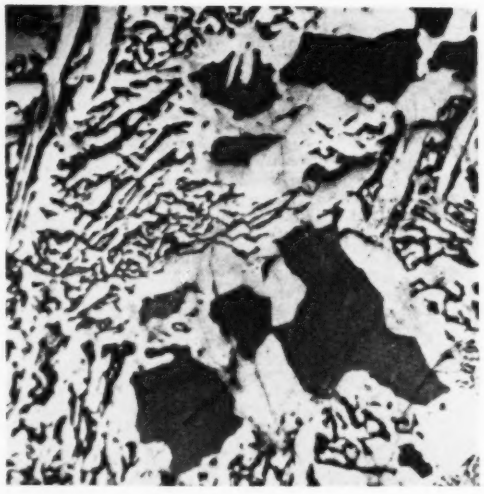
removal of traces of oxygen from the *H* iron by the aluminium. Discussion with Mr Ineson of BISRA led to the conclusion that vacuum fusion analyses would not solve the problem because, if deoxidation occurred, a suspension of alumina would probably be left in the alloy. It is, however, clear that, if the rise in freezing point is due to removal of oxygen, the initial depression of the freezing point of iron in pure Fe–Al alloys will be very small.



3 *Structure of furnace-cooled ingot, 52 at-%Al, showing the limit of solid solubility in α. Precipitate of ζ (light) in α, etched in 4% nital + HF* × 170



4 *Structure of furnace-cooled ingot, 60* at-%Al, *ϵ-eutectoid consisting of α (dark) and ζ (light) etched in 4% nital + HF* × 170



5 *Structure of furnace-cooled ingot, 67·9* at-%Al, *showing primary η (dark) and eutectic 1153°C, etched in 10% NaOH solution* × 50

The present results indicate slightly narrower freezing ranges for the α-phase alloys than those given by the dotted lines in Hansen's diagram. The liquidus and solidus fall to a peritectic horizontal at 1229°C (Hansen 1232°C) corresponding to the reaction $\alpha\delta + \text{Liq} \rightleftharpoons \epsilon$.

Annealing and quenching methods were used to determine the solidus in the equiatomic region, and the results confirmed those of thermal analysis.

The microstructure of the furnace-cooled alloy containing 52 at-%Al (Fig.3) showed precipitation of the ζ-phase in the $\alpha\delta$-solid solution, whose limit is therefore less than this at room-temperature.

The ϵ-phase forms peritectically at 1229°C, and decomposes eutectoidally at 1092°C (Hansen 1103°C). Figure 4 shows the microstructure of an alloy containing 60 at-%Al, and this consists almost entirely of eutectoid.

The present work confirms the diagram of Gwyer and Phillips[2] and indicates two eutectic horizontals corresponding to the reactions:

Liq (68 at-%Al) $\rightleftharpoons \epsilon(\sim 63{\cdot}5$ at-%Al) + η(69 at-%Al) at 1153°C

Liq (73·6 at-%Al) $\rightleftharpoons \eta$(70·5 at-%Al) + θ(74 at-%Al) at 1146°C.

These two eutectics are separated by a shallow maximum of the η-phase at 69·6 at-%Al and 1156°C (Hansen 72 at-%Al and 1173°C). The second eutectic replaces the peritectic shown at 1160°C in Hansen's diagram. The first eutectic (at 1153°C) gives rise to an irregular two-phase microstructure which has, however, no characteristic pattern (Fig.5). The second eutectic (at 1146°C) does not give rise to a finely divided two-phase structure, and it appears that growth of a solid phase continues on what were the primary crystals of that phase.

The θ-phase gives rise to a second shallow maximum at 74·6 at-%Al and 1150°C; after this, the liquidus falls to the aluminium-rich eutectic point at 652°C and 99 at-%Al.

ACKNOWLEDGMENTS

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REFERENCES

1. M. Hansen: 'Constitution of Binary Alloys'; 1958, London, McGraw-Hill.
2. A. G. C. Gwyer and H. W. L. Phillips: *J. Inst. Metals*, 1927, **38**, 35–44, 83.
3. N. W. Ageew and O. I. Vher: *ibid.*, 1930, **44**, 83–95.
4. A. Hellawell and W. Hume-Rothery: *Phil. Trans.*, 1957, (A), **249**, 417.
5. D. M. Poole and W. Hume-Rothery: *J. Inst. Metals*, 1953–1954, **82**, 490.

Iron and Steelworks Engineering
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Developments in electrical equipment for reversing plate mills

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SYNOPSIS

The essential functions performed by the electrical equipment on modern plate mills are basically unchanged from those performed by the electrical equipment on plate mills installed 30 or more years ago. Since these early installations, however, there has been steady development which has accelerated over the last decade.

This paper reviews recent developments, with particular reference to control systems because of universal interest in this field. Certain aspects have been selected for consideration which may be new to many people or which may still be controversial. The first half of the paper considers features of interest in main and auxiliary drives for large plate mills. The second half treats in more detail the problems of automatic control. 1809

MAIN DRIVE

Power requirements

WHEN CONSIDERING ANY DRIVE the power requirements and control requirements must be decided first. In the case of plate-mill drives the rating of motors necessary to carry out the rolling duty cycle must be determined first.

For known rolling programs the power requirements of the drive can be calculated fairly closely. Considerable information is available already on this subject.[1–4] Normally it is impossible to foretell the worst duty the mill will be called upon to perform during its life. The results of any calculations should therefore be compared with known practice. Table I gives the ratings of some typical modern plate-mill drives.

Method of rating

Occasionally misunderstanding still occurs over the output capabilities of a motor having a given name-plate rating. A note on this point is therefore appropriate, but first it is desirable to define terms.

Rms (continuous) rating The maximum power which the motor will develop continuously at rated speed without exceeding its rated temperature rise. It is also the horsepower equivalent at rated speed of the maximum value of rms torque that a duty cycle can have without the motor exceeding its specified temperature rise.

Sustained overload An overload sustained for a sufficiently long period (usually specified) to affect appreciably the temperature. Large reversing-mill motors in the UK usually have a sustained overload capacity of 25% for 2 h.

Working peak torque The maximum torque which the motor can develop for a specified number of seconds, repeatedly as part of a regular duty cycle. The factor determining this on dc reversing-mill motors is commutation.

Cut-out or circuit-breaker torque The maximum momentary torque that the motor can occasionally develop with no sign of electrical or mechanical damage. The overload protection is set to trip at this value.

In the UK up to 1955 the relevant British Standard for large mill motors was BS.169 (1925). The salient features of this for present considerations were that it specified a sustained overload capability of 25% for 2 h and a momentary test overload of 100% for 15 s. The armature temperature rises specified were 40°C for class A and 50°C for class B above an ambient

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TABLE I Typical modern plate-mill main drive ratings

Mill Nominal roll width, in.	Work roll dia., in.	Type	Ft/min Base speed	Top speed	*Drive* Rms. rating, hp	Rev/min Base speed	Top speed	Cut-out torque, tons/m	Physical arrangement
160	38	4-high single stand	350	900	8000	35	90	492	Twin motor (DA)
126	42	2-high roughing	440	880	4600	40	80	246	Single motor (SA)
150	39	4-high intermediate	410	1025	9200	40	100	492	Twin motor (SA)
150	36·5	4-high finishing	435	1090	9200	40	100	492	Twin motor (SA)
132	39	4-high single stand	460	815	10360	45	80	492	Twin motor (SA)
144	38	4-high single stand	400	1000	10000	40	100	492	Twin motor (SA)
98	32	4-high single stand	375	750	5000	45	90	240	Single motor (SA)
90	27	4-high intermediate	300	535	3650	42	75	183	Single motor (SA)
90	27	4-high finishing	390	530	2650	55	75	100	Single motor (SA)
86	37	Reversing rougher and plate mill	485	1160	7000	50	120	300	Single motor (SA)

SA = single armature, DA = double armature

air temperature of 40°C. Reversing-mill motors were designed to this standard except for the peak overloads which were normally a working peak of 2½ times full load torque and a cut-out peak of three times full-load torque.

It had been realized for many years that the sustained overload capacity was an unrealistic requirement for many industrial drives and that the temperature rises specified in BS.169 were unduly conservative for many applications. Following a study of this problem BS.2613 was introduced in 1955, replacing BS.169 and also BSS.168 and 226. Machines specified in accordance with this specification have no sustained overload capacity and have a continuous rating which is that equivalent to the maximum temperature rise above 40°C that can be maintained continuously and still give a satisfactory operational life to the machine. This is termed the 'continuous maximum rating' (CMR). The specification therefore allows no sustained overload and the momentary test overload for dc machines is only 50% for 15 s. The armature temperature rises above 40°C are 55°C for class A and 75°C for class B, by thermometer.

From 1955 to date the standard British practice for reversing-mill motors has been to design in accordance with BS.2613 except for temperature rises and overloads. For these factors the standard practice which existed before 1955 has been retained. There have been three main reasons for this. First, it was generally agreed that for heavy-duty motors where reliability was of prime importance it was desirable to be conservative in the temperature at which they were operated to ensure maximum reliability. Second, past experience has shown that it is often useful to have an inherent sustained overload margin in the motor for future contingencies and it was felt to be easier to do this by specifying a lower temperature rise than specifying a higher rating; previous practice was based on the lower temperature rise. Third, in many primary reversing mills the motor size was determined mainly by the peak load, and the rms load to which it is subjected is not likely to be much more than one-third of the cut-out torque. However, larger ingots and tandem rolling are changing this situation.

Curves A and B in Fig.1 show the continuous torque and working peak torque characteristics respectively for a typical UK reversing-mill motor with a speed range of 2½–1. Between base speed and twice base speed the torque falls inversely in proportion to the increase in speed above base speed owing to the reduction in field flux. Above twice base speed the cut-out torque starts to fall away more rapidly because at these higher speeds the worsening conditions for commutation cause the cut-out armature current to be reduced at the same time as the field flux is falling.

Standard US practice for reversing-mill motors is set down in standards published by the National Electrical Manufacturers Association[5] and is based on a 50°C rise for armature windings having class A insulation with no sustained overload. Curve C in Fig.1 gives the cut-out torque speed characteristic set down by NEMA.

Until recently, Continental practice tended to line up very closely with the UK practice but was rather more flexible in designing the motor to suit a particular job and in recent years this tendency has increased.

Up to the present there has been no disadvantage in adopting these conservative ratings for reversing-mill motors. Nevertheless, it is important that the margins which are being built into the machines are recognized when making decisions as to the size of motor that should be used. Three factors now affecting the design of electrical equipment for plate mills make it desirable that future policy towards rating standards should be flexible.

The first of these is the advent of automatic control. As mentioned later in this paper fully automatic control will make the duty cycle for a reversing mill far more predictable, and it will then be desirable that the factors affecting the continuous and peak output capabilities of a motor are clearly recognized and correctly evaluated. The second is the increasing importance of dimension limitations as the rating of motors for a given size of mill increases. The third is the use of mercury-arc converters for the supply of large plate mills, a use which is undoubtedly going to increase. To attain the most economical drive unit, the converter unit and the drive motor that it supplies must be correctly matched. Also, a standard which may be economical to maintain in the case of motors and generators may be uneconomical in the case of static converters.

AUXILIARY DRIVES

Power requirements

The total time for which a plate is actually between the main mill rolls is often less than half the time required to roll the slab to the required plate product. The rest of the time is taken up in removing the finished plate from the mill, bringing a new slab up to the mill, and handling the piece between passes. The time taken to perform these functions therefore has a very great

bearing on the output of a mill and this time is very much affected by the performance of the auxiliary drives. To enable the time to be kept to a minimum the drives must give rapid response of the auxiliaries to the operator's instructions. This means ample horsepower and good control.

The auxiliaries put no work into the piece being rolled. Therefore the power of the auxiliary drives is determined by the electrical and mechanical losses that occur within the auxiliary systems themselves. These comprise the normal running losses plus the additional losses that occur during acceleration and deceleration of the auxiliary drive and mechanism and also the piece where this is applicable.

In modern mills the peak power required is largely determined by the acceleration and deceleration torques required to give the necessary response. Also, because the acceleration and deceleration periods form a large part of the total operational time of the auxiliaries the rms rating of the drive is also mainly determined by these torques and the frequency with which they occur.

In a typical 144-in. plate mill with individual roller drives, the roller motors for the main tables are AISE frame 612 and to attain the maximum required rate of reversal they must develop a mean reversal torque of twice the standard full load rating for this frame.

Care should always be taken to check both the peak torque required to give the desired response and the rms torque of the heaviest duty cycle. Either can be the determining factor in motor frame size according to the type of mill and its duty.

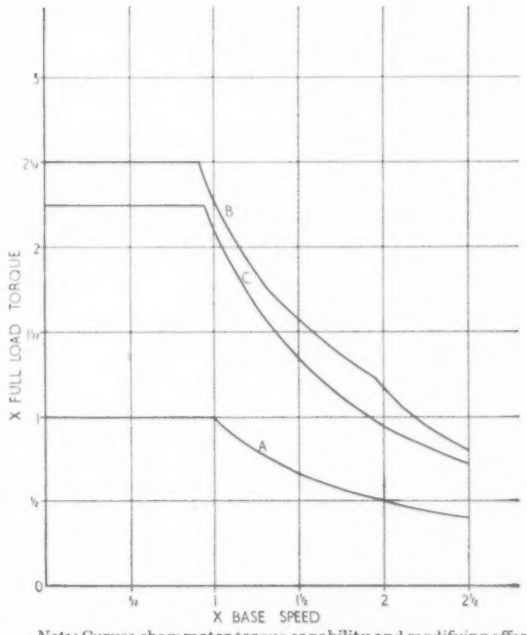
Motors and rating

General practice for large plate-mill auxiliaries is to use dc mill-type motors rated and dimensioned to AISE standards.[6] For reasons mentioned later the majority of auxiliaries are variable voltage and the motors used are standard 230 V shunt-wound 600 series, often run up to twice speed on double voltage to attain the maximum operating speed required.

The frequency of the duty cycle on many plate-mill auxiliaries is such that the rms torque rating would greatly affect the motor size if a totally enclosed motor were used. The motors for these auxiliaries are therefore force ventilated. This is now almost always so in the case of screwdown and roller-table drives. Where the motor inertia is a major factor in the total inertia of the auxiliary system, forced ventilation is also desirable to keep this inertia to a minimum by keeping the motor frame size to a minimum. In certain limiting cases the desired response could not be obtained without forced ventilation.

To achieve forced ventilation the general practice is now to provide an opening on the under side of the motor frame at the commutator end. The air is ducted to the opening through the motor bed plate and escapes out of the motor into the mill through holes at the opposite end of the motor.

As is the case with large slab mills, present practice with many large plate mills is to use a separate motor to drive each roll of the main table. Because of the space limitations which often occur in this application, modified mill-type motors of special electrical and mechanical design have been made available in the UK and in the USA for this application. These motors have only a single shaft extension and the terminal box is on the rear end shield. Thus the overall diameter is kept down to a minimum, enabling the minimum motor centres to be obtained.



Note: Curves show motor torque capability and modifying effect of control scheme

1 *Reversing motor torque characteristics*

POWER SUPPLY: MAIN DRIVE

Generators

The first large electric reversing-mill drive was installed on a cogging mill in Austria in 1907.[7] From this date until the last decade the Ward–Leonard system of control using an Ilgner set to supply the main drive has predominated for large reversing mills.

The dc motor with speed control by variation of its armature voltage supplemented by field weakening at full voltage cannot be rivalled for this type of drive. No other form of control can match the performance of this system, either in the degree of control that it gives or in the low level of energy losses.

The motor generator (MG) set has proved a very effective way of providing the variable voltage dc power. Further, until very recent years power supply systems in the UK had not sufficient capacity to absorb directly the very peaky load of a large reversing mill. It was therefore necessary to provide some form of buffer energy store. A mechanical store in the form of a flywheel has proved to be the only practical way of doing this.

As the capacity of the power supply systems in some parts of the world increased it became permissible to transfer the peaks of a large reversing mill straight back to the supply system. The flywheel was therefore omitted and a simple MG set used, driven by either a synchronous motor or an induction motor. One of the major advantages gained in so doing was the omission of the rotor losses which occurred in the induction motor rotor circuit when the speed of the Ilgner set dropped to release energy from the flywheel.

TABLE II Typical ratings for large plate-mill auxiliaries

Mill			*Auxiliary*								
				Drive							
Nominal roll width, in.	Approx. max. slab weight, tons	Type	Duty	Total no. of motors	AISE frame	HP of each motor, 230 V rating	Rev/min of motor, 230 V rating	Rev/min of motor at max. operating voltage	Control	Approx. speed of motion at max. motor speed, ft/min	Remarks
150	10	4-high intermediate rougher	Ingoing main tables	4	614	100	485	970	WL	800	Tapered rollers for turning
			Breast rolls	6	618	200	415*	150	WL	800	* 460 V rating
			Outgoing main table	2	614	100	485	970	WL	800	
			Screwdowns	2	616	150	460	460	WL	31½ in./min	
			Sideguards	4	606	25	650	650	Contactor	200	
144	22	4-high single stand	Main tables	34	612	28·7 hp at 211 rev/min on max. operating voltage (215 V)			WL	...	Special individual roller drive motors
			Screwdowns	2	616	150	460	920	WL	...	
			Sideguards	4	610	50	585	585	Contactor	...	
			Approach table	16	610	18 hp at 211 rev/min on maximum operating voltage (215 V)			WL	...	Special individual roller drive motor
			Runout tables (Nos.1–5)	79	610	18 hp at 211 rev/min on max. operating voltage (215 V)			WL	...	Special individual roller drive motor
			Runout table No.6	24	608	13·3 hp at 240 rev/min on max. operating voltage (215 V)			WL	...	Special individual roller drive motor
132	20	4-high single stand	Main tables	30	614	35 hp at 174 rev/min at max. operating voltage			WL	816	Special individual roller drive motors. Tapered rolls on ingoing and outgoing tables
			Feed rolls	6	618	75 hp at 156 rev/min at max. operating voltage			WL	816	Special individual roller drive motors
			Screwdown	2	618	200	420	1100	WL	75 in./min	Automatic position control
			Sideguards	4	610	50	550	275	WL	195	Automatic position control
98	...	4-high single stand	Work and turn table	4	610	50	550	1100	WL	...	Tapered rollers for turning
			Main work table	4	612	75	550*	550	WL	...	*460 V rating
			Breast rolls	2	610	50	550	1100	WL	...	
			Screwdowns	2	614	100	485	970	WL	...	

Mercury-arc converters

Where static forms of energy conversion can be used they offer several advantages over systems using rotating machines:

(i) they convert the energy more efficiently
(ii) their light load losses are less
(iii) less heat and noise are produced
(iv) less maintenance is required
(v) simpler foundations are required and a more flexible layout can be adopted. Also simpler building structures since the only heavy lifts are the drive motors
(vi) many static systems enable faster response control systems to be provided.

Against this, static devices have three main disadvantages which until recently have retarded their full application for reversing-mill drives:

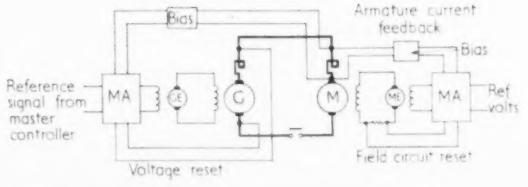
(i) a buffer energy store, equivalent to the addition of a flywheel to an MG set, cannot be provided. The power supply system must therefore take the full peak loads of the mill.

Also the most effective systems of voltage control give poor power factor at low voltages. This can considerably increase any voltage dips caused by the mill load peaks.

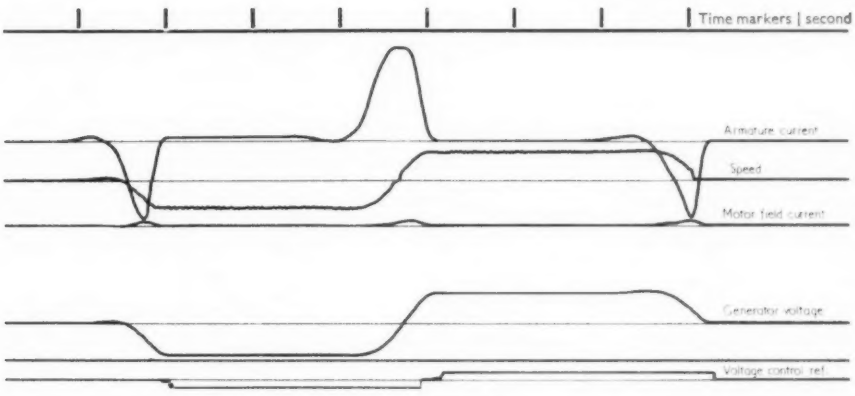
(ii) harmonics are introduced into the ac supply system
(iii) their unidirectional characteristics introduce extra complexity into the control, where reversing torques are required.

Many supply systems are now able to supply large reversing-mill drive loads without the necessity of a buffer energy store, and to absorb satisfactorily the harmonic effects which occur. This has removed the first two disadvantages and has opened up the possibility of using static conversion devices. The only static conversion equipment at the moment that can meet the requirements of reversing mills is the mercury-arc converter, and several reversing mills are now being or have been installed in the UK with their main drives supplied from mercury-arc converters. The largest is a twin drive for a 132-in. reversing plate mill with an rms rating of just over 10000 hp which will be going into operation in the middle of this year.

Estimated energy consumption figures for typical plate-mill drives supplied from Ilgner sets and alternatively from mercury-arc converters show savings in energy costs of up to 10% or more in favour of the converter.



2 *Plate-mill main drive, basic control scheme*



3 *Reversal tests, base speed to base speed, on 5000-hp mill drive*

In addition to the limitation caused by the supply systems there was also a natural conservatism to adapt new devices to such important drives. Modern variable-voltage feedback control systems acting through dc generators leave little to be desired in the control they provide for large reversing drives. Further, the large number of such systems now in use has meant that the control systems now available are the result of a steady development over a number of years and are a very effective tool which is reliable and simple for the job it does. However, considerable operational experience has been gained in the use of mercury-arc converters to supply continuous mills in the UK and considerable experience of their use in reversing mills on the Continent has proved their suitability and reliability in this field. With this experience now available and in view of the advantages offered by the use of mercury-arc converters, the possibility of using them is now almost always considered in any new reversing-mill project. The load cycle of a large plate mill may, however, be excessive for the capacity of the supply system in some cases. A careful consideration of the effect of the converter-fed mill on both the works supply system and the area supply system must therefore be made.

POWER SUPPLY: AUXILIARIES

Up to the late 1930's plate-mill auxiliaries were driven by ac or dc motors fed from the works distribution systems. In the UK dc motors were more usual because of their better control characteristics.

In recent years it has become general practice for most of the auxiliaries associated with the operation of large plate mills to be variable voltage controlled. This practice has been adopted for reasons of both economy and control, as is explained later. In most installations at present the variable voltage supply is achieved by the use of MG sets driven by synchronous motors or induction motors. Table II gives some typical ratings for large plate-mill auxiliaries and the arrangement of the supply MG sets.

Many of the advantages outlined for the use of static converter equipment supplying main drives apply also to auxiliaries. The mercury-arc converter is again the only static conversion device which is suitable for the supply of these drives but the case for replacing MG sets by mercury-arc converters is not so clear cut as it is in the case of main drives.

In capital cost the mercury-arc converter equipment usually shows no saving and often costs more than the equivalent MG sets. Further, the gain in running costs by using mercury-arc converters is often small.

MG sets are therefore being used in several cases for the power supply to reversing-mill auxiliaries, even though mercury-arc converters are being used on the main drive. However, there is undoubtedly a very strong attraction to static power conversion equipment. Some reversing-mill auxiliary drives are therefore being installed with mercury-arc conversion equipment, even though the initial cost may be greater. This trend will increase as the costs of static conversion equipments are brought down relative to MG sets.

CONTROL: MAIN DRIVE

Generator systems, rotating exciters

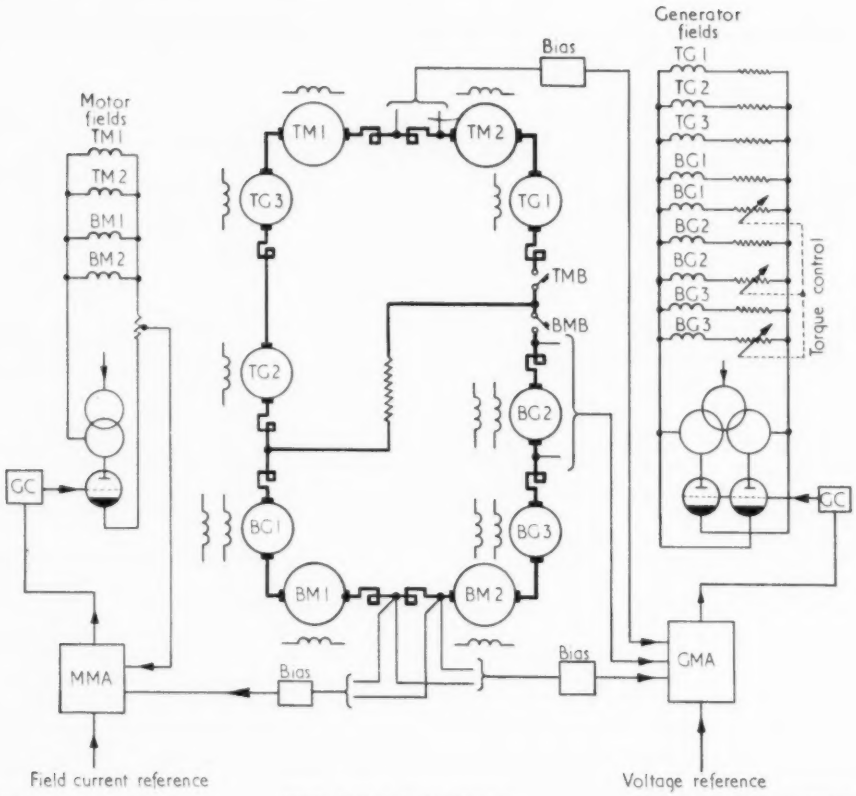
There are two main requirements of the control systems for a large reversing-mill drive:

(i) rapid response to the instructions given by the operator so as to give the best degree of control of the rolling operation

(ii) to enable the drive equipment to meet all the demands made by the operator, up to the maximum capabilities of the equipment, at the same time automatically preventing the equipment from exceeding these maximum conditions independent of any action on the part of the operator.

Figure 2 shows the basic type of control scheme in use on many plate mills. Separate closed-loop control systems are used for the generator voltage and for the motor field current. These are sequenced to avoid undesirable simultaneous operation. Fast-acting armature current limit control is provided acting on both the generator voltage and the motor field current control system. Both systems are designed to keep the ratio of peak armature current to mean armature current required to achieve a given change in speed, to a minimum. The rates of acceleration and deceleration are adjustable to suit the operation of the particular mill, as are the levels at which the generator and motor current limit circuits come into operation.

Modern control systems of this type can give a rate of response which will reverse the drive from base speed forward to base speed reverse in well under 1 s. Figure 3 shows a typical trace of a 5000 hp drive with



MMA motor magnetic amplifier
GMA generator magnetic amplifier
GC grid control
BMB bottom motor breaker
TMB top motor breaker
BG1, 2, 3 bottom generator 1, 2, 3
TG1, 2, 3 top generator 1, 2, 3
BM1, 2 bottom motor 1, 2
TM1, 2 top motor 1, 2

4 *Generator-fed twin-drive reversing mill*

a base speed of 50 rev/min, in which base speed reversal was obtained in just under 1 s. Reversal times as low as this are, of course, not often required and the control was adjusted to give slower operation. Once reversal times of $1\frac{1}{2}$ s or less are being considered, the important point is not so much the base speed reversal time but the degree of general controllability that the more rapid response gives to the operator.

Motor field system responses can give acceleration times from base speed to top speed of $1\frac{1}{2}$–2 s and similar deceleration times. Overall reversal times of between 3 and 4 s from top speed to top speed are quite normal unless the drive is a high-inertia drive where the limitation is armature current rather than the response of the control system. This total reversal time is somewhat less than the total motor field and generator voltage response times because although sequenced the two systems are in fact permitted to overlap to give the maximum overall response.

Generator system, static excitation supplies

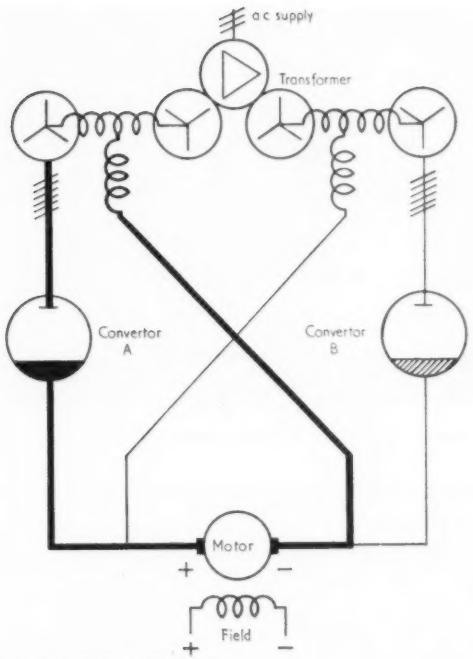
The advantages that have been stated for static power supplies for main and auxiliary drives also apply in large measure to static power supplies for excitation. In the basic scheme outlined above, magnetic amplifiers are used for the first stage of amplification but the main excitation power for the generators and motors is provided by a machine. For large reversing mills where excitation powers for the generators will range up to 25 kW and for the motors up to 80 kW, and where field forcing voltages of up to six or eight times normal full excitation voltage are required, the mercury-arc converter again offers the best static solution. Several large reversing mills using this form of excitation are in operation on the Continent and several are being installed in the UK.

Static excitation systems for large reversing-mill equipments may often cost more than the equivalent machine excitation system, even when mercury-arc converters are used, but in many such cases the extra cost has been considered justified for the advantages gained.

Figure 4 shows the basic control circuit for a large twin drive in which static excitation using convertors is being adopted for both generators and motors. In this particular case the convertors are capable of providing a field forcing voltage of eight times normal excitation voltage.

Twin motor drives

The powers required by modern plate mills are such that in the majority of cases twin motor drives are adopted. In this type of drive the method of speed control is exactly as has been outlined for the single motor drive. There is, however, the additional problem of co-ordinating the control of the two motors driving separate rolls. Two main operational features are required:



5 *Cross-connected converters*

(i) with the roll empty the motors should run at a constant speed proportional to the setting of the operator's control handle and the ratio of the speeds of the two motors should be very closely adjustable

(ii) under rolling conditions the two motors should share the load as equably as possible and should not cause the piece to turn up or down.

Experience has shown that the main factor in the operation of drives affecting the degree of bending of a plate is the relative speeds of the two rolls as the piece enters and while it is being rolled. A speed difference in the two rolls of only a few percent can have a major effect on the rolling of the plate. The most satisfactory rolling is usually obtained by making the two roll peripheral speeds equal and adjusting the motor to load share as equably as possible.

Mercury-arc converter power supply systems

When the mercury-arc converter is used as the power supply to a reversing drive there is, of course, one overriding factor that affects the whole design of the control system. A single converter equipment will only conduct current in one direction. A reversing-mill drive must be capable of developing torques in either direction for either direction of rotation.

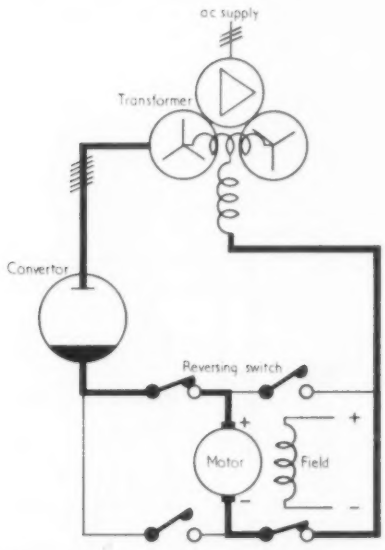
This reversing torque can be provided in three ways:

(i) arrange two mercury-arc converter equipments in cross connexion, one conducting in each direction (Fig.5)

(ii) provide an armature circuit reversing switch between the motor and converter (Fig.6)

(iii) reverse the motor field and so reverse the torque for a given direction of armature current (Fig.7).

Each of these systems has been used on reversing plate mills. Their main relative merits are:



6 *Single converter with armature reversing switch*

(i) cross connexion of converters as shown in Fig.5 gives the most satisfactory control but has the disadvantage that it costs more than the other two systems due to the additional converter equipment required

(ii) the armature reversing switch scheme employs only one converter and this is not so costly as the cross-connected arrangement. It requires the use of a large reversing switch and therefore is not so rapid as the cross-connected arrangement because of the dead time for the switch to operate. In some cases it has the advantage over the motor field reversal system of being slightly faster

(iii) the field reversal system has the same economic advantage as armature reversal of not requiring more than one convertor equipment and in addition avoids the use of a heavy current reversing switch. It has the disadvantage in some cases that the delay caused by the time taken to reverse the field is slightly longer than the delay which occurs in the reversing switch scheme.

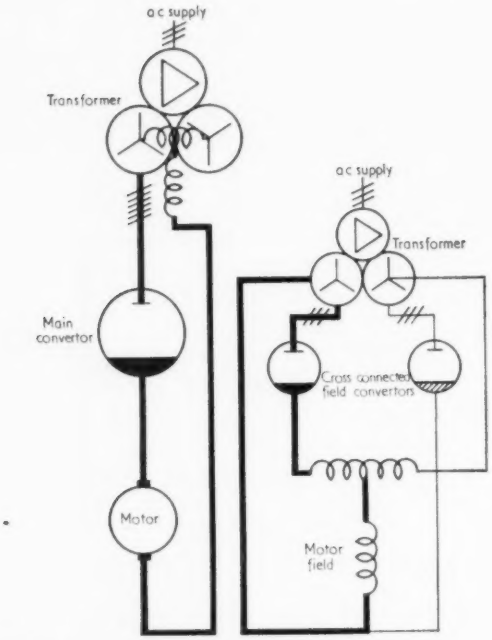
Figure 8 shows part of the converter equipment for the 132-in. plate mill to be commissioned this year. The main drive is a twin motor drive with a rms output of just over 10000 hp at 45–80 rev/min.

CONTROL: AUXILIARIES

As already mentioned, in the early plate mills the auxiliaries were driven by ac or dc motors with simple armature resistance control. This form of control, however, has two big disadvantages when applied to large high-output reversing mills:

(i) a considerable amount of energy is wasted in the armature resistances, and on a high-output mill the cost of this waste energy when capitalized more than pays for the increased cost of a variable voltage supply to each auxiliary drive

(ii) a modern variable voltage control system can give more rapid response and use the drive



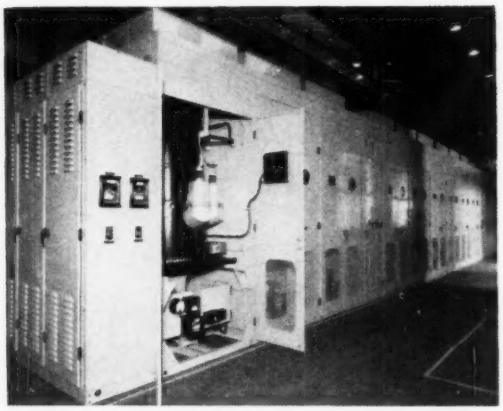
7 *Single converter with motor field-reversing*

nearer to its maximum capabilities. As the output increases this factor becomes more important, particularly when automatic control is applied to a mill.

The requirements for the control system for the main auxiliaries associated with a reversing mill are the same as those for the main drive. It must give rapid response and it must allow the drives to be used to their maximum capabilities whilst at the same time providing automatic protection.

Figure 9 shows the basic type of control scheme in use on many modern heavy plate mills. Since the majority of auxiliaries are basically constant torque drives and the peak loads required are those for acceleration and deceleration, all control of speed is done at maximum motor field by varying the generator voltage. Current limit protection is provided to enable the motor to change speed under maximum armature current without danger of excessive overload. A feature of many modern schemes such as this is that no frequently operated contactors or relays are used. The output from the driver's controllers is fed directly into the magnetic amplifier.

Where mercury-arc converters are used to provide a variable voltage supply to the auxiliary drives, schemes similar to those outlined for the main drive can be used. The two most normally used are either cross-connected converters or armature reversing switch. Motor field reversal requires additional equipment for motor field excitation which is not otherwise necessary in the case of auxiliary drives. On the simpler auxiliaries speed control systems are not required and the control is done on the voltage at the motor armature. Where fast control is required, then the cross-connected arrangement is preferable and it is particularly desirable where fast position control systems are required.



8 *Mercury-arc converter equipment for a plate-mill twin drive*

AUTOMATIC CONTROL

Introduction

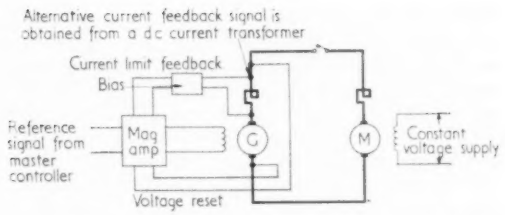
Up to this point main and auxiliary drives as individual units have been considered, i.e. the motors, their supply, and methods of controlling their speeds. On the first mill, installed at the beginning of the century, the operator's function was to carry out rolling of plate by controlling the speed of the drives. Modern electrical equipment so far considered gives the operator an extremely effective means of controlling the speed for each of the functions concerned in the operation of the mill. The basic function of the operator has, however, been left unchanged in that he still achieves his purpose by controlling only the speed of the various drives. Let us now consider the operation of the mill as a single production unit and the extent to which this unit fulfils its purpose in operating in the way so far outlined.

In the discussion that follows, the type of mill borne in mind is the wide four-high heavy plate mill of which several are at present being installed in the UK. A typical mill would receive slabs 4–10 in. thick and 56–108 in. wide, weighing from 1 to 7 tons. These would be finished to plates ranging from 60 to 120 in. wide and down to $\frac{1}{2}$ in. thick. Up to 45 passes may be involved which may be rolled in one stand or in two or three stands in succession, each with its own reversing drive.

Figure 10 shows the functions that have to be controlled by the operators on a typical plate mill with the equipment so far considered. It is the responsibility of the operators to roll the maximum output of plate of the required size, within given tolerances, with minimum stress to the mill equipment. They must do this by the co-ordinated control of the functions shown. The results obtained by the operators using modern systems which control the speeds of various drives are excellent. Nevertheless, marginal losses in the efficiency of operation occur for a number of reasons:

(i) inability of the operators accurately and consistently to move the screwdowns through small distances without loss of time owing to the need to 'jog' the drive to overcome stiction

(ii) failure to utilize efficiently the maximum capacity of the various drives, in particular the main and screwdown drives



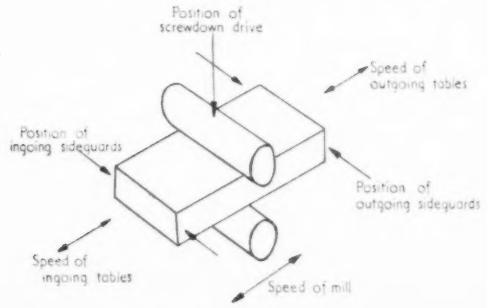
9 *Plate mill, Ward-Leonard auxiliary, basic control scheme*

(iii) loss of concentration of the operators. This can result either in lost time and errors in co-ordination of the various drives forming the production unit or inconsistent rolling procedure which can in turn affect the consistency of the product leaving the mill

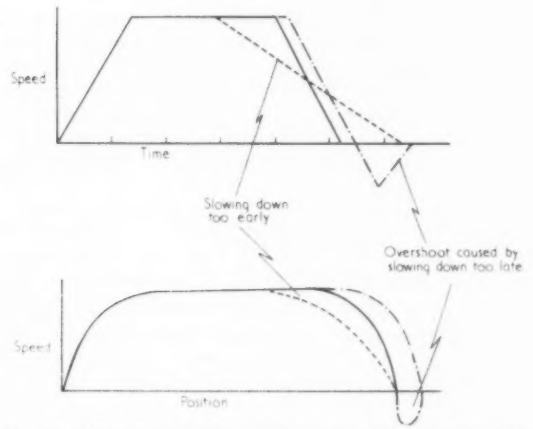
(iv) delays which occur when measuring thickness and width of plate

(v) errors of calculation which prevent rolling from being carried out efficiently in the minimum number of passes. For example, it is necessary for operators to determine the draft to be taken to roll a required length of plate in the minimum number of passes. It is also necessary for an operator to estimate the most efficient draft settings, to be taken on the final passes, to obtain a plate thickness within the required tolerances.

When reviewing the development of systems to control the speed of main and auxiliary drives it was pointed out that fast responses and inherent protection were obtained by adopting the principles of feedback control: in other words, removing from the operator the responsibility of watching how a drive performs the task required of it and including this responsibility within the control system. In the same way the effect of various factors leading to loss of operational efficiency can be reduced by taking more control functions from the operator and including them within the control system. Reorganisation of these functions can be divided into four main aspects. Logically the first is to replace the control of speed with a control of position, where it is position that matters, not speed: this applies to screwdowns and sideguards. The next is to provide automatic sequencing control which will accurately and consistently perform the operations of slowing down and stopping the mill and initiating the movement of screwdowns and sideguards. The third is the storage of information required to roll a particular



10 *Functions controlled by plate-mill operators*



11 *Ideal form for speed/time and speed/position characteristics for a screwdown drive*

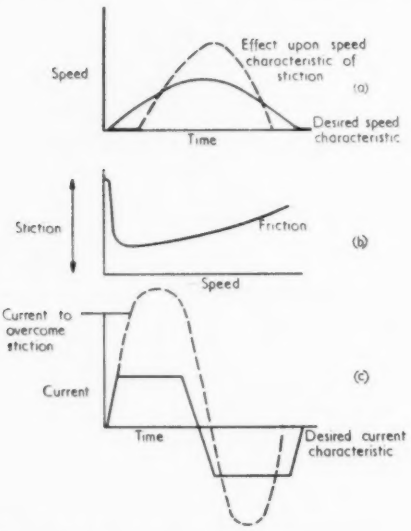
piece, so that the operator need then only refer his control functions to this information store. Such 'program control' provides consistent operation and thus a consistent product. In conjunction with automatic positioning and sequencing control a completely automatic mill can be obtained provided that all operations can be accurately determined beforehand. Since this is not always possible it is desirable, as the fourth main aspect of reorganization, to feed back, from the quality of the product, signals to modify the operation of the control system to produce the desired finished product. To achieve this the first essential is a means of measuring those qualities which are a function of the operation of the mill; the second is to interpret results obtained from such measurements and decide what modification should be made to the controls: for this a form of computer is necessary. In the rest of this paper these aspects of the logical development in the control of plate mills are considered to emphasize their more important operational features.

Position control systems

Screwdown

Of the various functions shown in Fig.10, screwdown drive is the obvious one to study first. It is this function that the operator has to control in every interval between passes, so that even if he takes only a fraction of a second too long at each adjustment a significant reduction in output can result. Figure 11 shows, in full line, the ideal form of the speed/time relationship and speed/position relationship when moving the screwdowns a comparatively large distance. The acceleration and deceleration rate should be a maximum, as dictated by the torque capacity of the screwdown motor. Although it is comparatively easy for an operator to ensure that maximum use is made of the torque capacity to accelerate, it is not so easy for him to determine the exact point at which deceleration should begin. If he decelerates too soon, as indicated by the dotted line in Fig.11, he will not make full use of the available torque. If he decelerates too late he will overshoot the desired position. In either case time will be lost in positioning the screwdowns.

When making small movements the effects of stiction and friction in the screwdown mechanism can prevent the operator from responding with sufficient



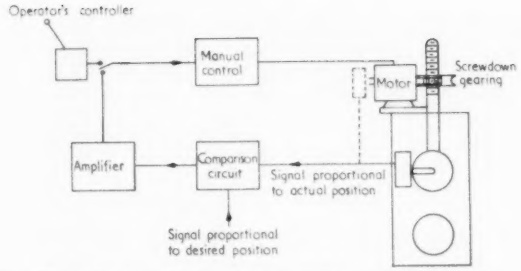
12 *Effects of stiction on a screwdown drive*

speed to ensure accurate positioning without overshoot. To obtain small and accurate screwdown movements the operator desires the drive to accelerate and decelerate at a comparatively low and controllable rate, as shown in Fig.12*a*. The effect of stiction, shown in Fig.12*b*, demands that the motor current rises to a comparatively high value (Fig.12*c*) before the drive can move. As soon as the drive starts to move, the stiction force is replaced by the lower friction value and the excess motor current causes the drive to accelerate at a higher rate than that desired by the operator (Fig.12*a*). To avoid this effect, which can result in an overshoot of the desired position, an equally inefficient yet more precise method of control is resorted to. This is a method of jogging or bumping the drive in small movements towards the desired position.

The position control systems now available overcome these problems and enable screwdowns to be accurately positioned in a minimum time. The use of a fast and accurate position control system also has two other advantages. First, it relieves the operator of having to drive the screwdowns during the interval between passes, so that he may concentrate on other functions. Second, it makes it much easier to position the screwdowns accurately and therefore results in a greater consistency of product. Where a preset control can be provided this advantage is further enhanced.

There are many different types of position control system which will meet all the requirements of accuracy and speed of response of plate-mill screwdowns. These may differ in the method used to detect position, i.e. synchros, potentiometers, or digital means, etc. and in the form of amplifier used in the feedback control system. Whatever the type of system used, however, there are certain fundamental features common to them all which must be considered in their design and application.

In essence, a position control consists of a normal manual control system embraced by a closed-loop position control, as shown in Fig.13. The position control loop consists of a means of inserting a signal



13 *Closed-loop position control applied to a screwdown drive*

proportional to a desired position and a means for measuring and comparing the actual position of the screwdown with the desired position. The difference between these signals is amplified and used to drive the system to the desired position.

It is essential, for both the designer of a position control and the user, to be able to define clearly the performance requirements of the screwdown position control. The most suitable way of doing this is to consider the performance under two headings; 'steady-state accuracy' and 'transient performance'.

Steady-state accuracy

The performance of a screwdown position control is affected both by the characteristics of the screwdown gear to which the control system is applied, and by the characteristics of the closed-loop control. It is desirable to take this into account when assessing the accuracy of a system, by making use of three terms; first, the steady-state accuracy as an assessment of the ability of the overall system to position the screwdown roll at any desired position; second, repeatability or consistency, to assess the ability of the system to roll plate accurately on the finishing passes when small trimming movements of the screwdown roll are required, and third, control system accuracy to assess the sensitivity of the closed-loop control both as a basis for designing the closed-loop control and as a common basis for comparing several systems.

Steady-state accuracy of a screwdown position control may be defined as the error to be expected between the actual position of the screwdown roll and the desired position. This figure takes into account all effects, both within the closed-loop control and within the screwdown mechanism, which would give rise to an error in position.

Repeatability or consistency of a screwdown position control may be defined as the error to be expected if an attempt is made either to repeat a given draft or to position repeatedly at the same position. This figure gives an assessment of the minimum tolerance, in plate thickness, which it is possible to roll and the consistency obtainable in finished product.

Control system accuracy may be defined as the smallest error in the position of the measuring device which the control system will attempt to correct when the system is stationary. The significance of this definition is that, for a given stiction effect, the control system accuracy is only dependent upon factors within the closed loop of control. It provides a direct measure of the sensitivity of the control system and forms a criterion for design.

The control system accuracy is a function of control

system amplification or gain. The higher the amplification in the system the smaller is the error in position required to provide sufficient torque to overcome stiction in the drive. This applies equally to continuous control systems, such as those employing magnetic or electronic amplifiers, and to discontinuous control systems using relays and contactors in cascade to amplify the error signal. However, in practice the dead zone effect of a discontinuous control system can put such systems at a disadvantage when compared with continuous control systems having no dead zone effects. This dead zone effect is the main reason for preference being shown to continuous control systems, for plate-mill screwdowns, where optimum repeatability and steady-state accuracy are essential.

For this optimum in performance it is desirable to obtain as high a control system accuracy as possible. However, a high system gain included in a system to achieve this can cause instability in either of two ways. First, an instability or hunting caused by the limited resolution of the measuring device which can cause the system to hunt between two discrete positions on either side of a desired position on the measuring device. Second, hunting caused by backlash within the closed loop of control. While it is possible to obtain measuring devices of high resolution, or in effect infinite resolution, the problem of backlash instability is more difficult to overcome. Attaching the measuring device to the screwdown roll, to measure its position accurately, has the disadvantage that the backlash of the screwdown mechanism is included within the closed loop of control. An alternative arrangement to avoid this (dotted line in Fig.13), is to attach the measuring device to the screwdown motor and to eliminate all backlash from within the closed loop. This allows a high system gain to be used to provide a high control system accuracy. The backlash in the screwdown gear outside the closed loop can then be taken up consistently in one direction by arranging the transient response of the system to be slightly different for the two motions of screwdown movement.

Transient performance

The transient behaviour of the screwdown should be considered under two conditions. First, when making the smallest screwdown movement normally required, and second, when making movements which would be expected to take the motor to full speed.

When making a small movement, not only is it necessary to overcome the force of stiction in the drive, but it is also necessary for the drive to brake quickly and accurately at the desired position. The system must respond rapidly to avoid the same difficulties experienced by the operator in controlling the high rate of acceleration when stiction is overcome.

When making larger movements, to position in a minimum time, it is essential to utilize the full available torque of the driving motor to accelerate and decelerate so that the drive runs at full speed for as long as possible. This desired characteristic is shown in full line in Fig.11. A low system gain will cause the drive to decelerate when the error in position is still comparatively large and will prevent utilization of maximum torque. Although a high system gain avoids this, if the gain is sufficiently high it is possible to hold the screwdown motor at full speed for too long and to overshoot the position because the operation of torque limiting circuits built into the system prevents excessive rates of deceleration. It is desirable to obtain an approach characteristic, plotted between speed and position, similar to that shown in full line in Fig.11, without having to limit the control system accuracy. This may be done by using circuit elements in the system which shape the approach characteristic and in effect limit the system amplification when the drive is running at speed. In practice such circuit elements can be adjusted to give the desired approach characteristic and still allow a high system amplification to be used for small movements of the screwdowns.

Optimizing performance of position controls

To obtain optimum performance, both in response and accuracy, a high system gain or system sensitivity is essential. A limit to high gain can be caused by dead-zone effects, limited resolution of the measuring device, or backlash within the system. These must be avoided or reduced. Special consideration must also be given to ensure that movements can be made without excessive overshoot caused by either stiction or torque limitations of the system.

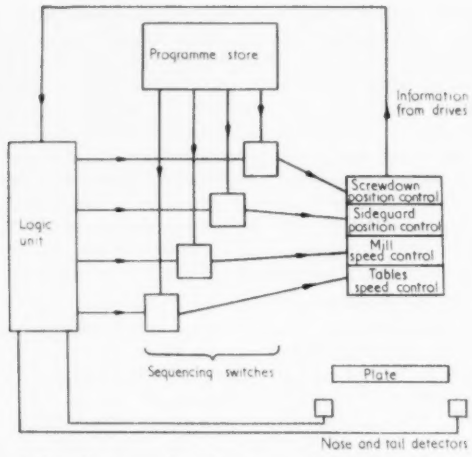
Method of operating a position control

With the application of a position control to a screwdown the method of operator control is of particular concern. If controlled directly by the operator the controls must at least be as simple to use as the speed control previously used by the operator. It is desirable that a setting for a following pass can be made while the work-piece is being rolled and that the actual screwdown movement is initiated by the operator when required. It is also desirable that settings should be made by touch without it being necessary for the operator to take his eyes from the mill.

There are two basic methods for calibrating the operator's controls; first, a control calibrated in terms of the roll gap setting, and second, a control calibrated in terms of draft of screwdown movement to be made on each pass. While either method of control can be applied to a plate mill, draft control is of particular interest. It provides in a simple control a means of easily setting the extremely small movements normally associated with finishing plate mills. It also provides controls directly calibrated in terms of the corrections given to the screwdown operator when the piece is gauged for size.

Sideguards

The required action of the sideguards control is one which allows the operator to move the sideguards to any desired position across the mill tables. Therefore all that has been said of a screwdown position control broadly applies to sideguard position controls. The most significant difference between the control of sideguards and the control of screwdowns is in the method by which the operator controls them. The most simple form of sideguards control is that using a control, such as a lever, to control the distance between the two sideguards heads rather than individual controls for each sideguard. This method can be extended to take advantage of the fact that on a plate mill, as opposed to a primary reversing mill, only a limited number of positions are required for rolling several passes. On a typical mill there are two control levers, one to set the sideguard position for guiding the plate into the mill and the other to set the sideguards to a wider position for receiving the plate as it leaves the mill.



14 *Automatic sequencing of programmed information*

Preset control

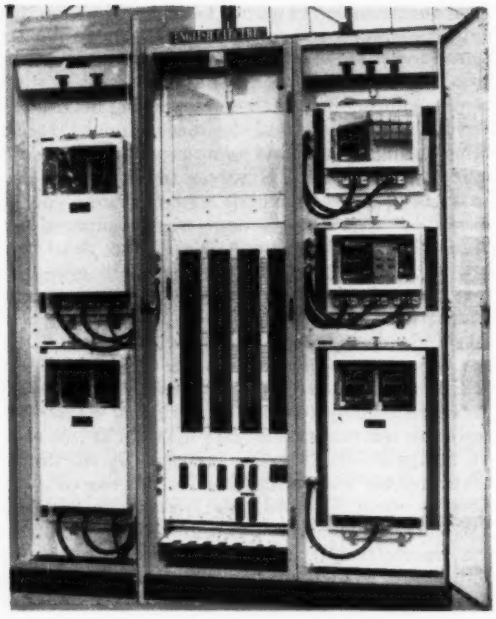
Often the positions required for sideguards and screwdowns for each pass in a program can be determined beforehand, particularly on roughing and intermediate plate-mills. If in such cases the control can be preset to store this advance information, then obviously a significant advantage is gained. The operator's job is made easier since now he has only to initiate the action of the auxiliaries concerned for each pass. Since each example of a given program will be rolled to exactly the same preset information, consistency is ensured. A set of rheostats, one for each pass, forms an elementary method for carrying this out. An alternative is to use a plugboard to select, by means of plugs, the required screwdown and sideguard positions to roll a given product.

It is obvious that this technique of pre-selection can be extended to embrace the remaining control functions on the mill complex shown in Fig.10. These are the mill and table speed settings associated with each pass rolled.

Sequencing

If the settings for speeds and positions of the various functions of a mill equipment are preset for all passes in a program, then the operator's job is greatly simplified. He has now only to supervise generally the operation of the mill and to initiate in the correct order or sequence the action of the various functions in accordance with the preset information. As has already been suggested, in carrying out this function the operator can fall short of optimum performance by loss of concentration. To avoid this, and to maintain a high operational efficiency, this function can be carried out for the operator automatically. The method of control is shown in Fig.14. The detection of the nose and tail of the work-piece can be detected by infra-red cells which feed information to a logic unit. Also fed to this unit are electrical signals from the various drives indicating whether or not a particular drive is in motion. From these signals the correct operation of the control functions is determined and the sequence of operations controlled.

With the introduction of such a unit to eliminate an important control function of the operator, it is necessary to evaluate the new role of the operator and determine the essential control that he must still maintain over the mill complex.



15 *Uniselector storage and sequencing equipment for two position controls and one speed control*

The operator now has an automatic mill or, in effect, an elementary robot which faithfully carries out instructions which have been given to it. From signals received from the drive and work-piece detectors it is able to carry out simple logic processes. However, if unforeseen factors upset the normal sequence it is imperative for the operator to be able to intervene at once. There are four methods by which an operator may wish to supervise:

(i) freeze the whole program, as he may wish to do when the plate is required to be checked for dimensions

(ii) modify the program for any one control, without affecting other parts of the program. An example of this would be to bias the position of the sideguards to assist the entry of a piece into the mill, or to bias the screwdown position to account for roll wear

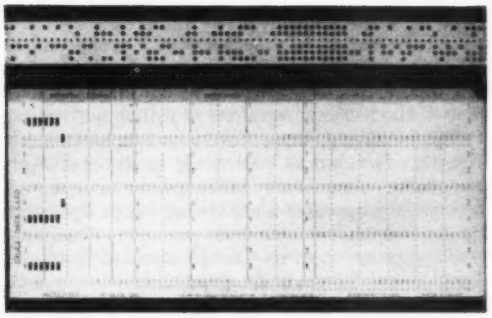
(iii) cancel the program to one function but carry on with the program of control of other functions, e.g. manual setting of the screwdowns to control the gauge of plate on finishing passes

(iv) cancellation of an entire program so that complete control may be returned to the operator.

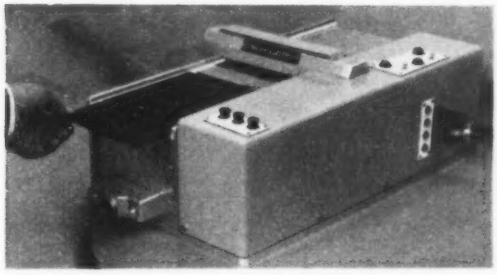
All four methods of operator supervision will normally be required, arranged in such a manner that the desired degree of supervision can be obtained by the operator easily and quickly. This is of the greatest importance in ensuring that the system has optimum flexibility.

Program control

Having established the use to which a storage system for the storage of one rolling program may be put, it is



16 *Information storage on punched card and punched tape*



17 *Special card reader developed for storing rolling-mill program data*

apparent that the storage of more than one rolling program would also have advantages. With such a storage system the operator can call for any one of a large number of programs, all of which would have been perfected on previous occasions.

The form of storage system chosen for a given application depends upon the number and size of programs, the time available to find a program, and the complexity and reliability of equipment.

There are four basic methods used for such systems:

(i) relay systems
(ii) punched card or punched tape systems
(iii) magnetic storage systems
(iv) electronic storage systems.

Examples of all four systems are in use either in the steel industry or in applications outside the steel industry.

Relay systems

A relay system can be characterized as one which provides a comparatively cheap and permanent store, of limited capacity, yet one which provides speedy access to information. Of particular interest are systems utilizing the uniselector relay, an example of which is the translator system developed by BISRA. The information is stored by wiring, on to a matrix of terminals, connexions corresponding to the various settings on the mill. The operator selects a program on switches calibrated in terms of the rolling parameters, such as ingoing and outgoing piece dimensions. In so doing, he causes uniselector relays to select the required program of terminals to roll that product. The technique used to find the programs is very similar to the techniques used in automatic telephone exchanges. Figure 15 shows a storage equipment, based upon uniselector relays, capable of storing the information for two position controls and one speed control and for sequencing this information. The particular equipment shown is capable of storing 50 programs with 15 passes per program.

Punched card or tape

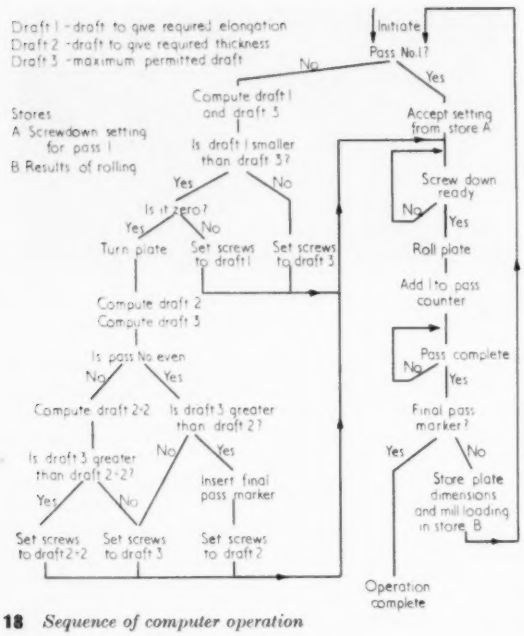
Information may be stored on punched cards or punched tape by forming a pattern of holes that can be read either by mechanical sensors or by photoelectric detectors. Figure 16 shows a type of punched card used widely in standard business data and computer applications, and next to it a punched tape used for recording teleprinter messages. Systems using punched card or tape are possibly the most flexible available for storing rolling-mill programs but can, if speedy access is required from a large store, be complicated by needing auxiliary sorting equipment. To appreciate fully the characteristics of the various systems which have been developed, it is desirable to subdivide further the punched card and punched tape systems.

Business card systems These systems utilize equipments developed for handling business office data. Use is made of standard business card readers and standard business card sorters. A number of systems in operation utilize several cards to store the information for one rolling program. These cards are read in rapid succession in a standard business card reader which transfers the information into a buffer store. It is retained here, for as long as it is required, and is available for controlling the mill pass-by-pass.

Special card systems To overcome the necessity of a buffer store, which can be a comparatively complex system, it is advantageous to utilize a card reader which allows the card to be read pass-by-pass, either on a matrix of hole detectors or by moving the card over single or double rows of hole detectors. However, the information to be stored for a single rolling program is often too much for one business card. To avoid the necessity of having to use several cards, one system uses a special card (shown with its card reader in Fig.17) which can be extended in length to accommodate all the information required for a single program. In applications requiring only a limited number of programs, the use of single cards can avoid the necessity of special card sorting equipment. To prevent damage to cards through constant handling, this system uses cards made of a more durable material than is normally used for standard business cards.

Punched tape Punched tape systems have been developed which are very similar to the card systems. However, with these systems some form of automatic sorting and tape handling is necessary. One such system utilizes a reel of tape containing several programs. The operator, by selecting his program on switches in much the same manner as with the uniselector system, causes the tape to be read at high speed to find the starting point of the program. The tape is then stopped and read pass-by-pass to control the mill.

Magnetic and electronic methods Magnetic or electronic methods for storing information are used widely in computer systems where their main requirements are maximum storage in the minimum space, high speed of access, and ability to retain or change the information quickly. To obtain these advantages the equipments are more complicated and costly than the systems already described. As yet, the requirements



18 *Sequence of computer operation*

for storing rolling-mill programs have not warranted the extra complexity of such equipments. However, their advantages may well be necessary in future applications of automatic techniques, particularly in the application of techniques of data handling and production control.

Measurements

The most recent developments of automatic control techniques for plate mills have been concerned with the development of suitable measuring devices. The intention is to provide equipment to measure accurately and quickly the length or width of plate and its thickness, so that this information may be presented in a suitable form to the operators. For plate width and length measurements where accuracy of measurement depends upon the accuracy of plate edge detection, photoelectric methods of detection appear to be the most promising. Several measuring units using this form of detection have been developed; one, for instance, is a method of mechanically traversing the plate with a photoelectric detector head and counting the number of electrical pulses supplied from the mechanism when moving from one edge of the plate to the other. For plate thickness measurement, methods utilizing X or γ rays have proved successful for the thinner gauges. But for thicker plates, the dangers to operators, inherent in powerful radiation sources, prohibit their use. A method of automatically calipering the plate with mechanical feelers appears to be most promising.

Although, as previously mentioned, it is first necessary to be able to present in a suitable form the measurements of the plate to the operator, the second step is to be able to feed these measurements to a suitable computer. Such a computer could then carry out calculations to assist the operator in optimizing his program to obtain in the minimum number of passes, plates of the required dimensions.

Computer techniques

It has been shown in practice that, by applying position controls to the screwdowns and sideguards and using a program store, the operator can be relieved of many of the routine functions of rolling a given work-piece. In so doing, these functions can be carried out at least as fast and as accurately as the operator and often more consistently throughout a long shift. However, the operator is still being called upon to take over control, either entirely or partially, when a desired rolling program cannot be decided beforehand. For example, on many mills producing close-tolerance plates it is unlikely that a program can be relied upon accurately to roll a plate to a length which, on turning, becomes the required accurate plate width. Even if this were possible it is unlikely that by programing the screwdowns to a given roll gap the plate will be accurately finished to the required thickness. The reason for returning to manual control is the failure of the program to take into account the many factors such as temperature of work-piece and mill spring which affect the finished dimensions for a given roll setting. Automatic means for measuring the dimensions of the piece and presenting this information to the operators will greatly speed up rolling by avoiding the necessity of stopping to take measurements manually. However, operator control will still not give rise to maximum operational efficiency, as no assistance is being given to the operator to interpret these measurements. Reliance is being placed upon the judgment of the operator not only to obtain the required plate dimensions but also to ensure that the plate is rolled in the minimum number of passes and therefore the minimum time.

Computer techniques are already being used to overcome similar problems in the steel industry. A typical example is the computation of the most economical lengths in which to cut a rolled section, from a knowledge of the rolled length and a stored knowledge of the order book. This problem has resulted in the design of a special computer, far simpler, faster, and more reliable than the larger and more expensive general purpose computer from which its development stemmed.

Although the application of computer techniques to plate mills is somewhat in the future, the possible course of evolution can be illustrated. In the first instance when rolling a plate for a length which on turning becomes the desired plate width, a computer could be used which can calculate, from a knowledge of the elongation of plate for a given draft, the total draft required to give the desired plate length by assuming a simple proportionality between elongation and draft. When rolling automatically, from settings obtained from a stored program, such a computer would provide the operators with an indication of the most suitable point at which manual screwdown setting should be taken over from the program. Also, an estimate would be available of the most suitable draft to be taken to obtain the final plate length.

With such a method, the answers obtained by the computer after each pass would be slightly incorrect due to various mill effects. The fact that after each pass the answer would be nearer to the right one can be used as a further stage in developing the computer technique. By allowing the computer to observe that

after each pass its previous evaluation was incorrect, it can be arranged to weight its answers and reduce the error after each pass. At this stage the necessity for the operator to decide when to take over can be avoided by allowing the computer to insert the last draft as soon as the estimated draft is within the capabilities of the mill, this being decided by the computer from measurements taken of mill loading and draft.

Rolling on the final passes to give a required thickness of plate can be calculated and controlled by the computer in much the same way as suggested when rolling for length of plate. However, it becomes apparent that the use of a computer to take over from a program store to roll the final passes can be extended to replace the program store almost entirely. The extra requirements for computer control are that rolling shall be carried out in the minimum of passes and that this number shall be odd, so that the piece finishes on the outgoing side of the mill. The computer operation illustrated in Fig.18 would now be:

(i) the computer has fed to it the actual ingoing dimensions and the required dimensions of the plate

(ii) program store provides the first screwdown setting which is then rolled

(iii) from measurements taken on this pass, the computer now has three calculations to make: (*a*) the draft required to give the total elongation; (*b*) the draft required to give the finished plate thickness; (*c*) the maximum draft permitted. This can be calculated from a knowledge of the loading of the mill and the draft taken on the first pass. The smaller of these draft settings is then used for pass two

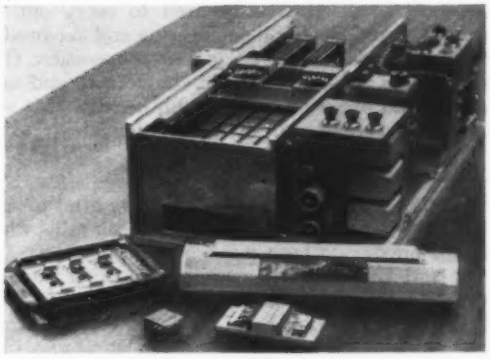
(iv) rolling proceeds until the draft for giving the desired elongation is the smaller and when this pass is rolled, the plate is turned

(v) the computer need now only consider the maximum allowable draft and the total draft required to give the desired plate thickness. However, the further requirement of finishing the plate on the outgoing side of the mill must also be considered. A simple way of doing this is to divide the answer arrived at for the total draft to give the final plate thickness, by two whenever the plate is on the outgoing side of the mill. When this figure is less than the maximum allowable draft, only two passes are required at this setting to finish the plate on the outgoing side.

Before such computer techniques can be applied to a particular mill, an extensive study must be made involving the equipment manufacturer and the user.

Reliability

Development of automatic control systems has been greatly affected by the question of reliability. In adapting techniques from other fields of application, efforts have been made to simplify the systems and to utilize reliable and well tried components. However, additional equipment such as storage equipment, no matter how reliable, obviously increases the possibility of faults occurring. To counteract this and to make such equipments acceptable in the steel industry, fault location techniques have been built into many of the systems mentioned. These techniques can be summarized as techniques of systematic and simple fault detection, location, and component replacement.



19 *Plug-in blocks of components for card reader, facilitating quick replacement of faulty component*

One of these techniques is used on a special card reader (Fig.17). In preparing the cards an extra space is made available for each pass. A hole is then punched, as required, to make the total number of holes for any one pass an odd number. Should an even number of holes be detected during rolling, a fault must have occurred and the system will freeze the mill and thus fail to safety. A special card can then be fitted into the card reader which systematically checks each hole detecting circuit to indicate the faulty one. By using plug-in techniques for blocks of components (as shown in Fig.19) the faulty unit can be quickly replaced.

CONCLUSION

The basic aim of all technical development is to evolve systems which will give a higher quality product, which will have a lower capital cost for a given performance, and which will cost less to run and maintain. Plate-mill electrical equipment is no exception to this and each of the developments outlined in this review has contributed to one or more of these aims. Future development work will have the same purpose, and the scope is wide.

Two main trends are clear: the increased use of static devices for power supply and for control and a continued increase in the scope of control systems and information handling systems to aid the human operator by carrying out, on his behalf, more and more of his controlling functions. These two trends will characterize the development of electrical equipment for plate mills over the next decade.

Static devices will continue to replace moving components including relays and switches as well as machines. This, together with the use of improved fault-finding techniques and plug-in unit assemblies will reduce shut-down time in spite of more complex circuits.

Extension of the coverage of control systems will first be to the automatic control of a single mill unit. It will, however, rapidly extend beyond that to the coordination of several mill units in a production line and integration of the control of mills with the processes before and after the mills. This field of development will have one very important aspect: the coordination of several engineering and administrative activities, which so far it has been possible to allow to proceed separately to a very large extent. In future

there will be an increasing need to carry out the mechanical and electrical engineering and the production planning as a single co-ordinated operation. Only by the close co-operation of manufacturer and user, designer and operator, will the full benefits that control system development offers be obtained.

ACKNOWLEDGMENTS

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REFERENCES

1. R. B. Sims: *Proc. IME*, 1954, **168**, 191–200.
2. P. M. Cook and A. W. McCrum: 'The calculation of load and torque in hot flat rolling', 1958, London, British Iron and Steel Research Association.
3. J. H. Taylor: 'Iron and steel engineer yearbook', 1956, 823.
4. E. C. Larke: 'The rolling of strip, sheet and plate,' 1954, London, Chapman and Hall.
5. NEMA Standard MG1–1959, Part 13.
6. Direct-current mill motor standards, AISE Standard No.1, 1957, 'Iron and steel yearbook', 1957, 941.
7. D. Selby Bigge: *JISI*, 1907, (I) 63–87.

Some aspects of plate-mill design and layout

A. Marshall

SYNOPSIS

Designing a heavy modern plate mill is a very complex problem and considerations facing the engineer responsible for the installation of such a mill are many and varied. Some of the most important features, e.g. slab conditioning, slab handling, details of mill design, and type of finishing equipment are discussed in this paper. Advances in design are so fast that they can outstrip the speed at which ideas can be incorporated in a mill installation and therefore some of the ideas set out here may be out-dated. 1806

DEMAND FOR PLATE in the UK and throughout the world was naturally high during the war years and continued at an unexpectedly high rate almost outstripping rolling capacity in the UK. As a result most plate rollers have almost simultaneously undertaken large developments in this field. However, owing to post-war circumstances, development by Germany has been more rapid and some six or more new plate mills have been installed. As a result Continental designers have been very active and many new features have been developed by them.

These conditions are, of course, inevitable since development depends largely on demand. Be that as it may, the plate mill of today is a much more complex and efficient unit than was ever visualized some 20 years ago. With the advancement of air travel has come a welcome interchange of ideas and techniques, and by this means the manufacturer can have access to engineering fields throughout the world.

Plate-mill design is a subject for the specialist but in this paper are set out some aspects of design and operation which face the purchaser of such equipment.

SLAB INSPECTION AND SCARFING

To attain good plate finish it is most desirable to ensure that all surface defects on slabs are removed before reheating and more and more attention is now being paid to the provision of facilities for slab scarfing. Various methods of scarfing are in use, the most common being the hand scarfing torch. Automatic cold deseaming machines are now on the market and it is possible to obtain multi-head machines capable of scarfing at the rate of 5–8000 ft² per 8-h shift with four nozzles. To feed this type of machine it is necessary to have a Ward-Leonard controlled feeder table, which adds to the cost. The third and most expensive type of machine is the in-line hot-scarfing machine which in any event has considerable effect on yield (2–4% loss) and requires a large amount of ancillary plant for gas cleaning and collection of metallics. The decision on the installation of such equipment can be made only on the basis of individual plant economics. One of the most important features of hand scarfing of slabs is correct handling methods and this can be achieved quite simply by the installation of a semi-portal crane within the confines of the overhead crane gantry. This unit can turn the single slabs as required by the scarfer and thus leave the OH crane free for other duties within the bay. A typical cross-section of such an arrangement is shown in Fig.1.

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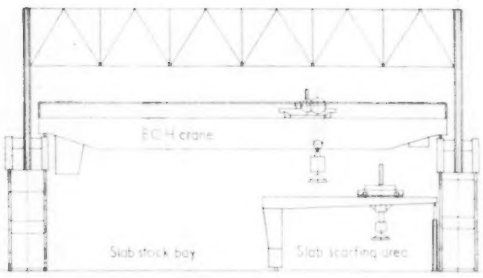
SLAB HANDLING

Depending on the geography of the plant, slab handling can be done in many different ways, e.g. if the primary mill is located some distance away from the plate mill then it may be better to split the storage between the two locations and transport all slabs by road, i.e. via fork-lift or straddle trucks. On the other hand if area is available at the plate mill all storage could be carried out there. It is extremely controversial whether or not all slab storage should be within a covered building. The use of fork-lift trucks is to some extent limited by the gradients which can be negotiated, and when carrying pay loads of 20 tons or more a first-class road is required. One plant on the Continent uses 20-ton Ross Carriers for the transporting



1 *Typical slab preparation arrangement*

of all slabs and the following performance has been attained on a good level road:

(i) distance travelled, 3 km
(ii) fully loaded, max. speed 30 km/h
(iii) unloaded, max. speed 40 km/h.

The round trip of 6 km takes 30 min and two carriers work all round the clock on transportation. Tonnages handled by two machines are of the order of 60000 tons/month.

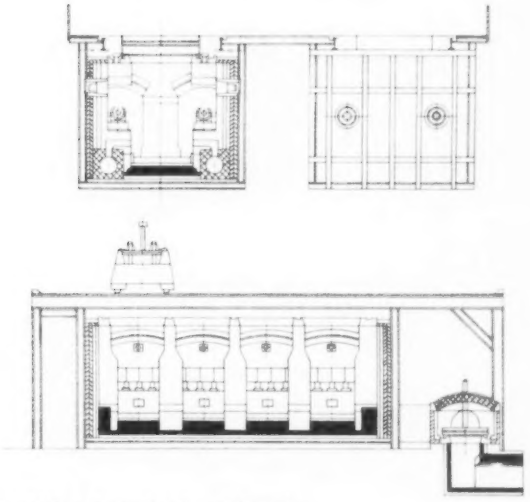
The management of the plant were very satisfied with this handling system and claimed the cost of operation to be about one-third of the equivalent rail service.

This application is quite satisfactory for their plant layout but Consett decided against this method because of varying levels and severe gradients between the primary mill and the plate mill. To feed the new plate mill at Consett with slabs, trains of special wagons will be used, each having a pay load of 80 tons with eight wagons making up a train. In this manner only two trains per shift will be necessary to feed the mill with sufficient tonnage for it to operate fully. About 50% of the slab storage will be outside and this material will be handled by fork-lift truck. The slabs stored inside the building can be handled in three different ways, (*a*) by magnet, (*b*) by C-hook, (*c*) by slab tongs.

The type of handling equipment in any layout, will, of course depend on the magazine facilities and furnace-charging arrangements.

SLAB FURNACES

The three- or five-zone semi-continuous furnace is being successfully used for plate mills but these furnaces, if heating slabs of 10 in. and over in thickness, give unsatisfactory results owing to the danger of welding slab edges and the consequent poor 'soaking'. In our present plate-mill practice two rows of slabs are worked, and this brings in difficulties in sizing, grading, and planning of the furnace throughput. One furnace seen in Germany has been fitted with a false set of skids outside the furnace so that program planning to give greatest hearth coverage can be attained. With semi-continuous furnaces high production per unit capital cost is attainable and also high hearth-area efficiency is possible. Hearth coverage with little planning can be as low as 50% but with efficient planning can be increased to about 80%. Ease of charging and withdrawing is an added advantage and even heating of successive slabs through the furnace is attained. If using small slabs, three skids instead of the usual two are a distinct advantage. Piling of slabs in a narrow furnace can give a lot of trouble, usually at the roof nose of the soaking zone. An idea for assisting in clearing blockages and repairs etc. might be to have a removable roof (in sections) so that crane access is available.



2 *Eight-cell oil–electric soaking pits*

Steam raising on furnace skids has become common practice in Europe and the equipment necessary can be installed on almost any semi-continuous slab furnace without major alteration. The furnace then becomes in effect a boiler, subject to annual inspection in the normal way.

To heat slabs of over 10 in. thickness it is necessary to install additional equipment such as conventional wash-heat type of furnaces, bogie furnaces, or soaking pits. Wash-heat furnaces are not very economical since to obtain large outputs requires a number of furnaces and additional charger facilities. Bogie-type furnaces are popular with certain plate manufacturers but at Consett a combination of semi-continuous furnaces and oil–electric soaking pits is preferred.

Slabs too short for the semi-continuous furnace can be charged quite effectively and brought up to 1150–1200°C using oil, with the final soaking being done by electricity. The eight-cell unit shown in Fig.2 is capable of handling 3000 tons of slabs per week. One further advantage that this method has for our particular application is that the eight-cell unit will form the first of a battery of soaking pits for future ingot heating. The advantages of this type of pit are the simplicity of design, limited amount of civil work, capital outlay, and speed of installation.

MILL DESIGN

Plate-mill design has achieved remarkable progress over the past 30 years and has advanced progressively from the old single 2-high stand to the present-day 4-high high-production unit. The engineer today who is not a specialist on rolling-mill design has to study and sift all new ideas and produce the combination of features which he thinks will give the best results and this is very difficult to do since the mill manufacturers are introducing alterations in design at regular intervals.

TABLE I Comparison of plate mill details

Item	Oberhausen	Hattingen	Bremen	Salzgitter	Domnarvet	S.I.A.G.	Lorraine Escaut Longwy	Algoma	Sheffield Steel	Homestead	Luken's	Bethlehem Sparrow's Point	Consett
Max. slab weight	15 tons	25/50 tons	25 tons			30 tons	25 tons					12 tons	18 tons
Max. plate length	100 ft		100 ft			90 ft	60 ft					70 ft	90 ft
Max. plate width (sheared)	118 in.	157½ in.	130 in.			142 in.	150 in.					108 in.+	120 in.
Plate thickness range (sheared)	0·197–1·57 in.	0·15–1·57 in.	0·197–1·25 in.	0·125–1·6 in.		0·315–1·57 in.	0·2–1·5 in.						0·125–1·5 in.
Slabs													
Max. width	59 in.						52 in.					60 in.	60 in.
Average thickness	6 in.						7 in.						7 in.
Max. thickness	16½ in.		12 in.				10 in.						24 in.
Max. length	118 in.		118 in.				147 in.						120 in.
Ingots													
Max. weight		50 tons				30 tons	25 tons		5·125 tons				25 tons
Min. weight		3 tons				6 tons	3 tons		2·23 tons				8 tons
Slab furnaces													
Type and No.	1 side discharge	1 rust	1 rust	2 rust			1 rust	1 rust	2 rust	2 rust	4 in and out	2 rust	2 rust
No. of zones	5	5	5	2			5	5	3				3
Fuel used	B.F. gas	B.F. and C.O. gas	Fuel oil	B.F.+10% C.O. gas		All ingot rolling and slab ingots heated in soaking pits	B.F. and C.O. gas	B.F. and C.O. gas	Natural gas			Nat. gas, C.O. gas and fuel oil	Fuel oil
Length of furnace	75 ft		90 ft				86 ft						95 ft
Width of furnace	23 ft	20 ft	23 ft 6 in.				17 ft		18 ft	22 ft 6 in.		23 ft	23 ft
Capacity		30–40 tons/h	100 tons/h	40–50 tons/h			45–55 tons/h		40 tons/h	75 tons/h		70 tons/h	100 tons/h
Max. thickness slab	10 in.	10 in.	12 in.	10 in.			10 in.		11 in.	10 in.	10 in.+	10 in.	10/12 in.
Vertical edging stand													
Supplier	Schloeman	Sack	Demag	Roughing stand with vert. edger Demag (126 in. roughing mill–1952 0–40–80–2/200 m.t.)		Demag							
Type of drive	Under	Over	Under	Over		Over	No vertical edger						
Motor sizes	2×750 kW					2×150 mt	installed	2×1000 hp					
Roll diameter	39½ in.	39½ in.	39½ in.	31½ in.		41½ in.	but	42 in.					
Roll length	39½ in.	39½ in.	39½ in.			39½ in.	roughing	15 in.					
Roll pressure	300 tons	700 tons	200 tons			800 tons	stand						
Roll opening	130 in.	157·8 in.	134 in.	31½/116 in.		157·5 in.	installed						
Distance between edger and mill centre line		32 ft 9 in.	12 ft 6 in.			49 ft 3 in.							
Roll speed						3·93–4·26 ft/s							
Plate mill													
Supplier	Schloeman	Demag	Demag	Schloeman	Sack	Demag	Mesta	Blaw Knox combined blooming and plate mill under construction	United	Mesta	Luken's	Mesta	Davy United
Date of supply	1957	1955	1957	1952	1938	1956	1955		1951	1942		1957	
Length of work rolls	130 in.	165 in.	134 in.	126 in.	130 in.	148 in.	156 in.	114 in.	130 in.	160 in.	206 in.	160 in.	132 in.
Dia. of work rolls	35½ in.	38½ in.	38½ in.	36½ in.	31½ in.	37½ in.	38 in.		38 in.	36 in.		39 in.	38 in.
Dia. of back-up rolls	57 in.	72 in.	58 in.	55 in.	51½ in.	57 in.	60 in.		58 in.	59 in.		59 in.	60 in.
Type of bearings, work rolls	Timken roller	Timken roller	Timken roller	Timken roller	White metal	Timken roller	Timken roller		Timken roller			Timken roller	Timken roller

Table I (continued)

Item	Ober-hausen	Hattingen	Bremen	Salzgitter	Donnar-vet	S.I.A.G.	Lorraine Escaut Longwy	Algoma	Sheffield Steel	Home-stead	Luken's	Bethlehem Sparrow's Point	Consett
Type of bearings, back-ups	Morgoil	Demag oil	Morgoil	Morgoil	White metal	Demag oil	Timken roller		Timken roller			Morgoil	Morgoil
Height of roll lift	23½ in.	43½ in.	35½ in.	14 in.		27⁹ in.	20 in.			20 in.		20 in.	24 in.
Cross-section of housing	97² in.							800 in²	1000 in²	1000 in²		1100 in²	1200 in²
Rolling speeds	0/7·12/14·2 ft/s												
Motor speed, rev/min	0–40–90	0–40–80	0–40–80	0–40–80		0–40–80	0–35–90	0–40–90	0–40–120	0–40–80			0–45–80
Motor sizes	2×	2×	2×	1×		2×180 m.t.	2×200 m.t.	2×	2×				2×5180 hp.
	200 m.t.	230 m.t.	200 m.t.	175 m.t.				4000 hp	3500 hp				2×246 m.t.
Screwdown speeds	1·57 in./s	2·3 in./s						12 ft/min blooming 190 ft/min plate		0·8 in./s			1·25 in./s
Production													
Planned capacity	35000 tons/mnth	60000 tons/mnth	30000 tons/mnth			20000 tons/month							
Actual production	27000 tons/mnth	50000 tons/mnth	9000 tons/mnth	50000 tons/month		10800 tons/mnth	22500 tons/mnth		560 tons/shift			70000 tons/mnth	40000 tons/4
Yield, %						71·5	67						
ingot/plant	...	72	...	70		...	81		...			...	
slab/plant	83	...	86	82					82			80–81·5	

3 *Arrangement showing nested chock design*

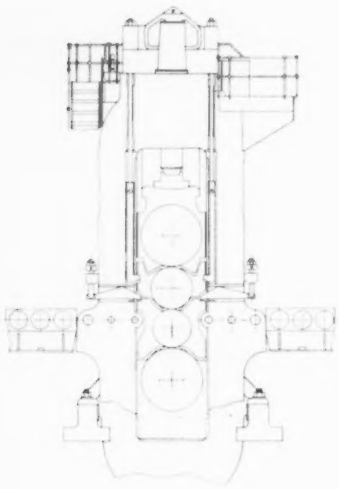
The modern mill stand has over recent years gone up in size until the weight of the main housings almost exceeds casting capacity in the UK. In fact the design of some stands has been limited and more or less governed by the weight of housing which can be cast. Foreign manufacturers do not appear to have had this problem.

For purposes of detail, the main stand may be split into the following sections: (*a*) rolls and chocks, (*b*) roll balance, (*c*) breast rolls, (*d*) main tables, and (*e*) descaling.

Rolls and chocks

The size of back-up rolls in a modern plate mill has increased until the capacity of manufacturers has become strained, although it is fair to say that certain manufacturers are spending money on extensions to cater for the larger rolls. This is a very real problem for the rollmaker since the number of plate mills in the UK are few and the anticipated tonnage life of a back-up roll is so great that demand is small. Even so, some engineers prefer larger back-ups, but here we must consider the housing size. It can be readily seen from Table I (prepared from details observed on visits to plants all over the world) that the maximum size back-up roll is of a capacity which taxes the rollmakers. Sleeved rolls or composite rolls as they are called, have been used but do not appear to be completely successful. It is essential to have a sleeve of minimum 9 in. thickness and, depending on the type of bearing used, this is sometimes difficult to achieve. On the Demag mill at Hattingen, which must have the largest back-up rolls in the world, i.e. 72 in.×157 in., a sleeved roll is used, sleeve thickness being 10 in.

Selection of bearings for these large rolls is, to a large extent, a matter of engineer's choice, and experience. Morgoil bearings, although expensive in initial cost when including the oil system, are trouble-free in service and require less effort for movement. This enables the main drive to be slightly reduced in size



4 *Alternative means of roll balance*

and saves capital cost, and offsets the extra cost of Morgoil bearings and necessary oil system. Since the size and weight of work rolls is, by comparison, small, then the choice of bearings is usually automatic, i.e. roller bearings.

The choice of chock design depends on many things, i.e. back-up roll diameter, type of bearing, method of balance, descaling system, etc. Figure 3 shows what the author considers the best arrangement, but this is only possible if the designer is not limited by housing casting weight (depending on mill size). Top work-roll chocks nested in back-up roll chocks in the method shown can do away with long troublesome rams between work-roll chocks especially on a high-lift mill. A further advantage is that of self-aligning work relative to the back-up roll. This design is still being used successfully on the Continent. With unnested chocks, differential wear on the housing wearing strips is bound to take place. Another interesting and pleasing feature of this arrangement is that it is possible to ambush the descaling pipes and sprays in the stripper guides, the descaling pipes being withdrawn at each roll change. Maintenance of sprays then becomes a simple operation and ensures routine inspection. It is also virtually impossible to damage the sprays since they are completely nested and hidden. When designing the new mill at Consett we were not fortunate enough to be able to include all these features, owing to housing size, although nesting of the top sprays has been achieved.

Roll balance

In the modern arrangement for roll balance, the weight of the top work roll and chocks and the top back-up roll is taken on the parting cylinders and the weight of the top back-up roll chocks is taken on the top balancing hangers. It must be remembered that when the slab enters the work rolls, the tendency is for the top back-up roll to lift in its respective bearings. For roll changing, however, pump capacity and pressure are increased to carry the weight of the back-up roll.

Another system of balance which is being used successfully on the Continent is to suspend the whole top-roll assembly by means of rods connected to crossheads mounted on the screwdown platform, the rods sliding up and down in slots cut inside the housing face. This has disadvantages in that it splits up the wearing plates in the housing and also gives rise to some difficulty during roll changing. In this method the bottom assemblies are held down by means of hydraulic cylinders mounted on the outside of the housing, the holding-down levers being positioned through slots cut in the housings and seating in notches cut in the chocks (*see* Fig.4).

Breast roll design

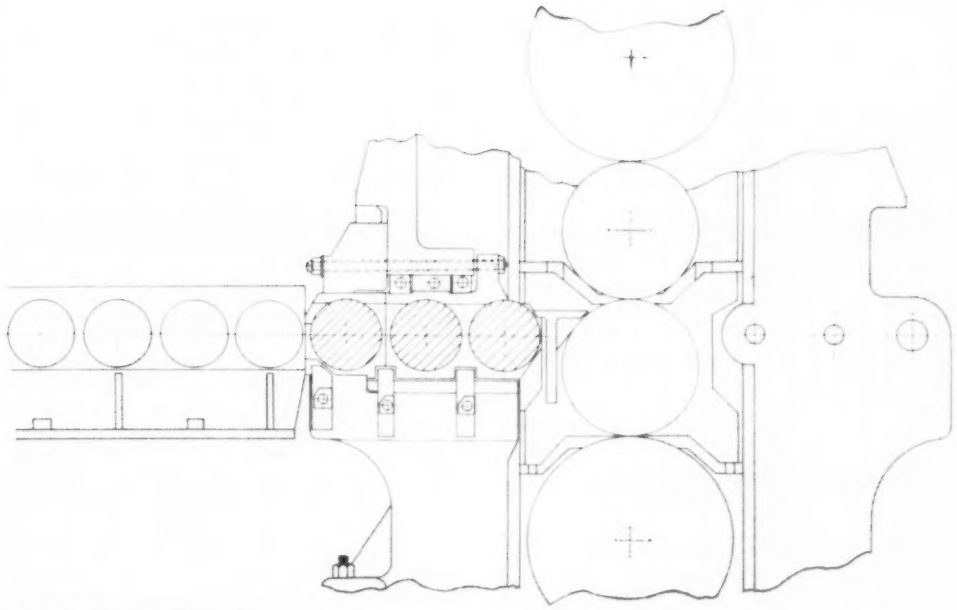
In designing a plate mill to roll very narrow slabs the first breast roll must be very close to the bottom work roll and this presents a major problem. There is a limit to the closeness of the centres which depends entirely on the design of mill stand. Breast rolls can be designed on the disc principle but even this does not solve the problem of close centres and the only solution is to install two small removable rollers. Breast-roller design has posed problems to the designer and operator since it is the section of any mill which perhaps takes the greatest shock loading and therefore possibly demands the most attention to maintenance.

Many methods have been used to try and overcome the excessive wear and tear that breast rollers get but as yet no solution has been found except regular maintenance. Some designers favour spring-loaded bearings but so far spring loading has been only partly successful since the springs have been placed in a vertical plane under the roller. Some attempt to position the springs in a plane in line with the angular loading of the roll has been made but so far no successful installation has been operated. Other designers favour an entirely different approach and use the argument that if the breast rolls are built absolutely solid with the housings then the loading is transferred to the one piece of the mill which is most likely to absorb it without difficulty. Two mills are now operating in Japan with this feature and the intention is to change the breast roll assembly only once per year.

We have decided to use this method on our plate mill and it can be seen from Fig.5 that changing a breast-roll assembly is a major job and involves the removal of the work rolls (and bottom back-up) and the use of a special porter bar.

Main tables

The design and development of main tables for primary mills and plate mills has been an accumulation of good and bad experience over many years culminating in what is the latest trend, individual drive rollers. In the early post-war years, design of main tables followed closely on previous practice but it was quickly found that due to increased slab and ingot weights an entirely different approach had to be made to the problem. The change from line-shaft drive to individual drives was not made in one step, but the first major change in design was by having two or three rollers grouped together thus giving, with the reduction of some gearing, a consequential reduction in maintenance troubles. The next step was to have individual drives making sure that motor power on, say,



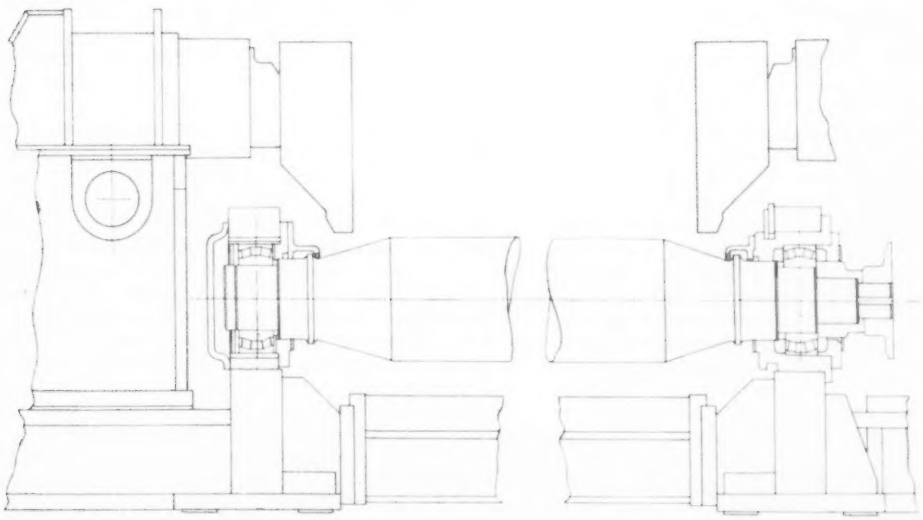
5 *Arrangement of breast roll assembly*

two rollers was sufficient to move the ingot or slab. Even in these earlier designs, the trouble of keeping the bearings tight was not obviated until solid side frames were used thus obviating bearing caps and keep bolts. This design, which is the most modern in the world, has many advantages since roll changing is comparatively simple and loosening of keeps and subsequent wear on gearing is non-existent. The application of this design to plate mills gives a slight disadvantage when changing one or two rollers owing to the proximity of the sideguards. This can be seen from Figs.6 and 7 showing the arrangement to be adopted at Consett. However, since the chances of a roller failure are slight it is a justifiable risk.

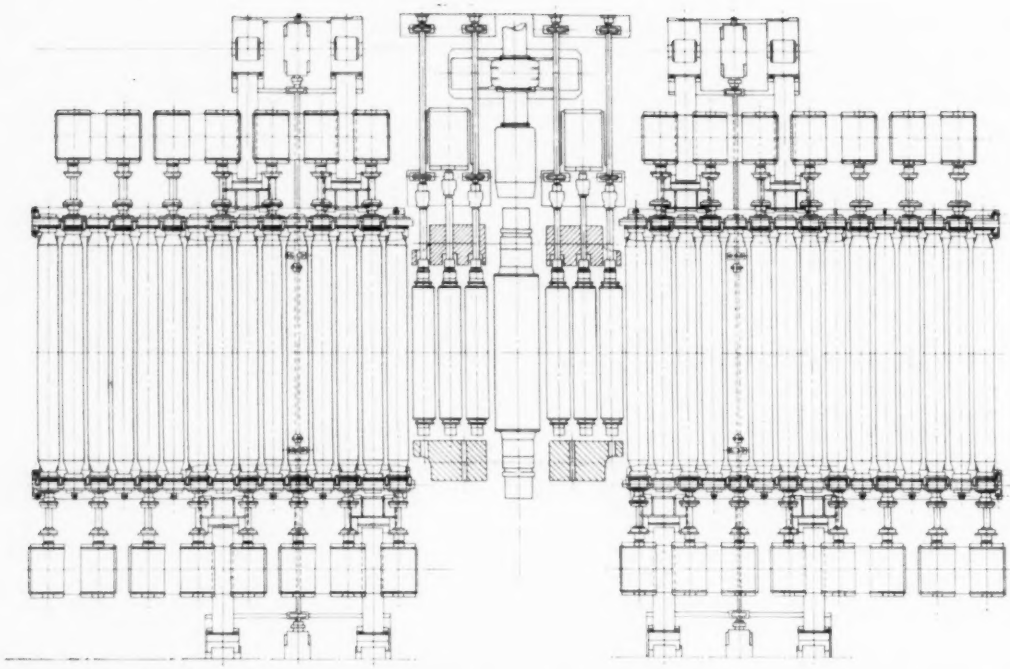
A further development of this principle has been introduced whereby individual driven rollers are also gear-coupled in groups of four so that power from all motors can be transmitted through one roller. The gearing is outside the table framework and is therefore not subject to heavy wear and tear.

Descaling

One of the most important contributions to good surface quality in plate production is efficient descaling and scale breaking. A number of ways of achieving this are in use but the main two are, (*a*) primary scale breaking in a two-high stand followed by efficient high-pressure water sprays at the mill, and (*b*) primary scale disposal by a descaling box and then, as in the first arrangement, scale removal at the 4-high stand by high-pressure water.

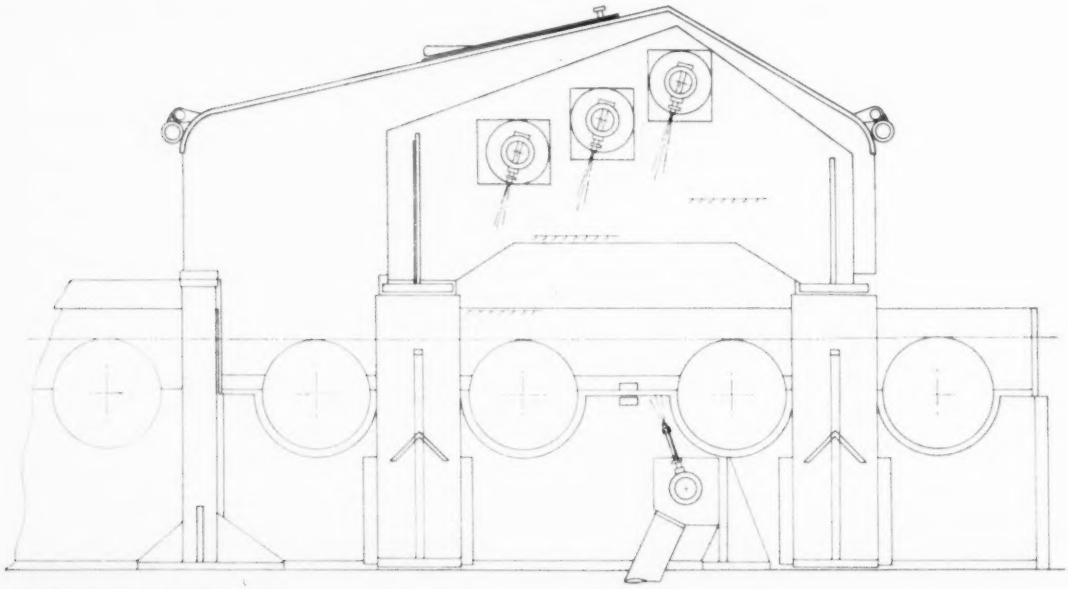


6 *Section through main tables*



7 *Plan view of main tables*

During a recent study of mills throughout the world we found a strange state of affairs existing where some mills were installing scale-breaking stands and yet others were actually removing these stands or by-passing them and depending entirely on scale water at the mill. One mill on the Continent has installed a very efficient descaling box which handles slabs up to a maximum of 8 in. thickness. This is a relatively simple means of primary scale breaking and can be installed quite cheaply. It comprises a mild-steel box straddling the roller table and heavy single-header banks of spray nozzles, top and bottom. Since the final layout of the Consett mill will include a 160-in. 4-high stand and a very heavy edger, it was decided to use the descaling-box method but with certain modifications as shown in Fig.8. In this case three top headers are included to cater for slabs ranging from 4 in. to 20 in. in thickness, each header having specially designed sprays for its



8 *Section through descaling station*

duty. The heavy scale removed from this station will be transported via a water flume into the main scale pit. Descaling at the 4-high stand will be by the conventional method but with the scale pipes nested in the top work-roll strippers. This can be seen from the cross-sectional view shown in Fig.9.

SHEARING EQUIPMENT

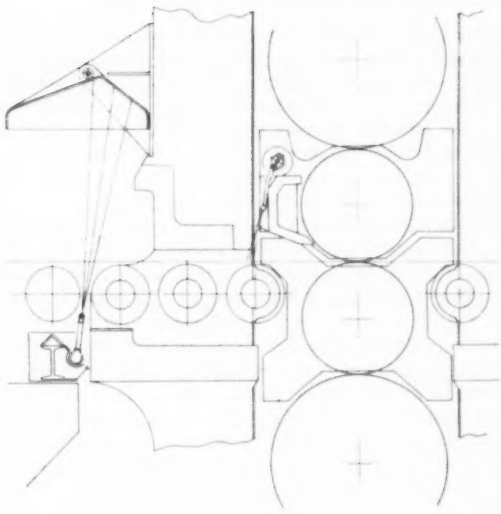
Design of shearing lines for a high-production plate mill is very important since the output of the mill depends on the speed of plate disposal and rate of handling through the shearing lines. It is essential to install efficient cooling banks to ensure that good flat plates are delivered to the shears. In this respect the conventional hot bank fitted with heavy C.I. grids is in my opinion the best arrangement and gives even air flow around the plate and ample support to enable the plate to take natural flatness.

Since speed of shearing is essential, many attempts at automatic marking have taken place but without a great deal of success. Automatic marking by machine is taking place on the Continent but while the actual execution is satisfactory, speed is lacking and further experiments are being carried out. We have included an automatic marking machine in our new layout and this machine embodies all the latest design features. In an attempt to speed up the operation of the automatic marking machine, designers have arranged to cross-traverse the two marking heads a short distance only, i.e. about 9 in., thus giving two marks at either end of the plate for lining at the cross-cut shears. While this is satisfactory for a single plate, it is not convenient if a plate is to be slit and, therefore, a full line across the width of the plate is required. Many problems on automatic marking are still unsolved although a good deal of research is still going on.

Perhaps the most remarkable stride made in finishing-equipment design is in the field of shearing and scrap disposal but even on this subject there is a wide disparity of views. Since the largest number of plate mills built since the war is on the Continent, it is reasonable to look in this direction for the greatest advance, and we carried out a very close study of all that is best and worst in this subject.

The latest development in shear design is the rocking-type shear where the blade opening in the stationary position is parallel. The shear design is clean and tidy and from the engineering point of view is first-class. The main advantage of the rocking-type shear is that resulting scrap has less bow than that arising from a conventional shear. While the manufacturers will claim no bow in the scrap, the author has not yet seen scrap without bow, although the resultant bow is less. However small the reduction, it is a great help in disposal and with the modern rotary shear, automatically fed from a slat-scrap conveyor, it can be handled without too much difficulty.

Scrap disposal is of prime importance, and like many other problems depends to a large extent on local conditions. Some people prefer to load the scrap on discharge from the rotary scrap shear direct into charging boxes which does away with double handling, while others prefer to convey the scrap to one central loading point inside the confines of the mill. The latter installation could be very costly in the way of equipment and maintenance and does not appear very attractive. Like all these problems, it is one which is not easily solved, but if one adopts the philosophy that a plate mill is installed to roll plates as a high-production unit and that something like 15–20% of its charged slab weight is in the form of scrap, then the soundest scheme appears to be to take the scrap out of the building by the cheapest possible method so that no hold-up of the mill will occur, and then load it into charging boxes in a central location.



9 *Section through mill stand, showing descaling pipes*

Rotary shearing and slitting of light plates, i.e. maximum $\frac{3}{4}$ in. thickness, is now a well established practice although shear design has not changed very much since the earlier rotary shears were introduced. Advance in design has been mainly in scrap cutting, guides, and scrap disposal. One attempt to design a complete rotary shear combined with a slitter has been made and in fact the machine was installed and put into operation but was not successful due to curling of the slit edges. It is essential when slitting plate to allow one outside edge of the plate to move freely on its width otherwise edge curling will result. The success ful and established method of slitting plate is to position the slitter about 20 ft beyond the rotary shear.

On the subject of finishing equipment, particular attention should be paid to plate disposal since at this point the important issue is not solely the tonnage to be handled but the number and range of size of plates to be disposed of. If the range is reasonably small and long runs of similar sizes are frequent, then full use should be made of plate stackers and pilers, which are now quite common. In the case of a mill which is jobbing for a large percentage of its time and where the number of customers is large then a good, cheap, practical solution can be found by using semi-portal cranes for the preliminary sorting of the banks. Use of semi-portal cranes will enable maximum use to be made of loading-bay cranes.

In some cases, portal cranes have been used in place of transfer banks, the cranes being controlled from a central control desk. This system is possibly fast enough for long plates but questionable for large numbers of small plates.

SOME COMMENTS ON PLATE-MILL LAYOUT

In any large integrated steelworks, space is usually at a premium and therefore the engineer responsible for laying out a modern plate mill is normally confronted with many problems. Almost without exception, layouts are affected by local geography and therefore the ideal is rarely achieved. Apart from installing the correct machinery to produce the right product, the most valuable asset in any plate mill is space.

Distances between furnaces and mill can be excessive but usually there is good reason for this, e.g. as at Consett, to allow for the future installation of a 160-in. roughing stand and a heavy edger. In order to overcome this, a very fast rope-hauled bogie is being installed capable of speeds up to 600 ft/min.

Changes of direction, no matter for what purpose, should be avoided since they involve expensive equipment and also expense in doing work. Distribution of plates to and from shearing lines is most important and particular attention should be paid to discharge of material into the sorting and loading bays.

For an output of 10000 tons of plates per week a sorting and loading area of some 100000 ft^2 is necessary. An advantage in some layouts has been to have a sunken loading dock, thus enabling the slinger on the floor to see inside the wagons.

Since the loading-bay cranes are probably the hardest worked, particular attention should be paid to their design. The most useful type is the rigid, rotating-mast crane, equipped with magnet beam and power-adjusted magnets. These units may be expensive but give the operator that degree of control and flexibility essential for speedy and efficient working.

The advent and rapid development of road vehicles of all shapes and design must also play an important part in any modern mill layout. Road access to any vital part of the plant is a distinct advantage and if possible should be provided.

Apart from the main features of plant, many smaller problems face the engineer, such as fuel supplies, offices and amenities for staff and workmen, communications, maintenance shops and stores, water-treatment plant, and a host of minor details essential for an efficient high-production unit.

STAL *in English*

Numbers 7 and 8 (July and August 1959) of the cover-to-cover translation of the Russian journal *Stal'* have been published, and subsequent issues should appear at about monthly intervals. Principal contents of no.8 are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

IRONMAKING

Composition of the gas phase in the production of fluxed sinter from Krivoi Rog ores

Movement of charge materials and optimum blast-furnace working conditions

Improving blast-furnace charging equipment

STEELMAKING

Semi-commercial 15-ton rotary steelmaking furnace

Optimum teeming rate and temperature for sheet-metal ingots

Heating feeder heads with exothermic mixture

Symposium on heat insulation and heating of ingot feeder heads

Charging-machine rail ties

ELECTROMETALLURGY

Metal stirring by induction in electric arc furnaces

ROLLING AND TUBE PRODUCTION

Increasing steel roll-wear resistance by hard-facing

Better thermal shape control for sheet-mill rolls

Distribution of specific stress in the deformation zone during piercing

METAL SCIENCE AND HEAT-TREATMENT

The influence of manufacturing process parameters on the properties of cold-rolled transformer steel

Properties of electrical steel with phosphorous additions

Chromium–zirconium steel 45KhTs

Medium-alloy finely textured electrical steel

Influence of final rolling temperature on the properties of St3sp steel plates

ECONOMICS AND ORGANIZATION

Discussion on methods of assessing labour productivity

SMALL COMPONENT PRODUCTION

Calculating the adjustment of the deforming device in the manufacture of twist-resisting ropes

A self-adjusting drawplate

HEAT TECHNOLOGY

Controlled parameters and controlling factors during OH steelmelting

GENERAL

The function of lead in the hot galvanizing process

THE IRON AND STEEL INSTITUTE

Annual General Meeting 1960

The 91st Annual General Meeting of the Institute will be held in London on Tuesday to Thursday, **3–5 May 1960.** Sessions will be held at the Royal Commonwealth Society, Northumberland Avenue, WC1, at Caxton Hall, Caxton Street, SW1, and at Church House, Great Smith Street, SW1. The main technical sessions will be devoted to a symposium on wide strip production, at which papers from Australia, Italy, the Netherlands, the UK, and the USA are to be presented and discussed. There will also be a session devoted to electric-arc steelmaking.

The papers for the symposium are to be preprinted, and will in due course appear, together with reports of the discussions, in the Institute's Special Report series. The volume will be supplied at 65*s* per copy; one set of preprints will be sent to all those whose order for a bound volume is received by the Secretary before the meeting. Preprints of papers will NOT be available separately.

The paper for the session on electric-arc steelmaking is also to be preprinted; copies will be supplied without charge to all those registered for the session.

The full programme of the meeting is as follows:

Sessions at the Royal Commonwealth Society, Northumberland Avenue, WC1

Tuesday, 3 May

10.30–11.30 Formal business:
Presentation of the Report of Council and Statement of Accounts for 1959
Presentation of awards and prizes
Announcements
Election of new members.

11.30–12.30 Induction of the new President, Mr W. F. Cartwright
Presidential Address

SYMPOSIUM ON WIDE STRIP PRODUCTION

Session A: Future requirements of the vehicle and tinplate industries

2.30–5 Presentation and discussion of the following papers (NOT to be preprinted):
The future requirements of the vehicle industry by W. E. Lambourn
The future requirements of the tinplate industry by C. E. S. Sutton

Wednesday, 4 May

SYMPOSIUM ON WIDE STRIP PRODUCTION (continued)

Session B: Steelmaking for wide strip

Sessions at Caxton Hall, Caxton Street, SW1

10–12.30 Presentation and discussion of the following papers:
Oxygen steelmaking for flat-rolled products by R. W. Evans
Open-hearth steelmaking practice for flat-rolled products by S. J. Dougherty and R. Duffett
Production of steel with intensive use of oxygen in the open-hearth melting shop at Cornigliano by M. Foresi and G. Massobrio
Quality control of wide strip mill products by J. H. van der Veen

Session C: Hot rolling of wide strip

2–4.30 Presentation and discussion of the following papers:
Design and layout of a modern hot strip mill, by J. J. Beese, M. F. Dowding, C. Sturdy, and A. A. Thomas.
Operations of the wide strip rolling mills at Fairless works by K. L. Johanssen

Thursday, 5 May

SYMPOSIUM ON WIDE STRIP PRODUCTION (continued)

Session D: Cold rolling and heat-treatment of wide strip

10–12.30 Presentation and discussion of the following papers:
Metallurgical principles and practice in the manufacture of cold-reduced tinplate by W. J. S. Roberts
**The rolling of very thin tinplate* by M. D. Stone
Some engineering and operating problems in the conversion of a tandem cold-reduction mill to higher speed by W. H. Corlett, S. A. Lewitt, and S. Gray
Short-time annealing of capped, rimmed, and semi-killed wide strip by P. N. Richards
Annealing of cold-reduced sheet and coil by H. H. Ascough

Session E: Coatings

2–4.30 Presentation and discussion of the following papers:
The application of tin coatings in the manufacture of tinplate by G. E. Jones
Galvanizing. A review of the hot-dip processes with some reference to electrogalvanizing by H. Edwards, E. D. Harry, and E. Jenkins
Plastic-coated steel by S. S. Carlisle and W. Bullough

Session at Convocation Hall, Church House, Great Smith Street, SW1

STEELMAKING IN ELECTRIC-ARC FURNACES

Thursday, 5 May

10.30–12.30 Presentation and discussion of:
The new electric melting shop of Steel, Peech and Tozer by A. Jackson and R. S. Howes (to be preprinted)

* Provisional title.

The determination of gases in metals

A meeting on **The determination of gases in metals,** organized by the Society for Analytical Chemistry in conjunction with The Iron and Steel Institute and The Institute of Metals, is being held at Convocation Hall, Church House, Great Smith Street, London SW1, on Tuesday and Wednesday, **3–4 May 1960.** The meeting is open to members of the three societies and their guests.

Those wishing to attend should apply to the Secretary of The Iron and Steel Institute, 4 Grosvenor Gardens, London SW1. There is no registration fee, but those wishing to obtain preprints of the papers can only obtain them by subscribing to the bound volume of the proceedings of the meeting, which is to be published later in the year at a cost of £3 3*s* 0*d*.

The programme of the meeting is as follows:

Tuesday, 3 May

2.30–4 Session I: presentation of the following papers:
**Sampling of liquid metals* by T. B. King
The determination of oxygen in metals: a review by W. T. Elwell
The determination of gases in metals by vacuum-fusion by J. E. Still
The determination of gases in metals by the semi-micro vacuum-fusion technique by A. Parker

5–7.30 Session II: Presentation of the following papers:
An assessment of carrier-gas methods for the determination of gases in metals with particular reference to steels by C. E. A. Shanahan
The determination of oxygen in beryllium by activation analysis by R. F. Coleman
Emission spectrometric determination of oxygen, nitrogen, and hydrogen in metals by V. A. Fassel
Joint discussion of papers presented at Sessions I and II

Wednesday, 4 May

9.45–12.45 Session III: presentation and discussion of the following papers:
The determination of nitrogen in metals: a review by J. D. Hobson
The determination of nitrides in metals by H. F. Beeghly
The determination of hydrogen in metals: a review by R. Eborall
The determination of hydrogen in cast iron by J. V. Dawson and L. W. L. Smith
An improved carrier-gas technique for the determination of hydrogen in steel by F. R. Coe and N. Jenkins

2.15–4.45 Session IV: presentation and discussion of the following papers:
X-ray emission analysis and the determination of gases in metals by T. Mulvey
Application of internal-friction measurements to the study of gases in metals by G. M. Leak
General discussion.

* Provisional title.

Annual Dinner 1960

The Annual Dinner for Members will be held at Grosvenor House, Park Lane, London W1, on Wednesday, **4 May 1960,** at 7 for 7.30 pm. The Right Honourable Richard Wood, P.C., M.P., Minister of Power, has agreed to propose the toast of *The Iron and Steel Institute and Industry.*

Applications for tickets (price £2 10*s* 0*d* each, wine not included) should be sent to the Secretary as early as possible.

Autumn General Meeting 1960

The Institute's Autumn General Meeting will be held in London on Tuesday (all day) and Wednesday (morning only) **29 and 30 November 1960.** There will be two main technical sessions, devoted to the aerodynamics and hydrodynamics of furnaces and converters and to martensite respectively. Papers have already been invited, and no additional contributions are required in the form of formal papers. However, contributions to the discussions will

be welcomed from those working in these fields.

Following the Autumn Meeting, on the afternoon of Wednesday, **30 November,** all day on Thursday, **1 December,** and the morning of Friday, **2 December,** the Institute is holding a *Symposium on Steels in Reactor Pressure Circuits*, in association with the British Nuclear Energy Conference. Full details of the symposium will be circulated shortly.

Joint meeting in Sheffield

A joint meeting of The Iron and Steel Institute, the Sheffield Metallurgical Association, and the Society of Non-Destructive Examination was held at the Engineering Lecture Theatre, Applied Science Department, University of Sheffield, St George's Square, Sheffield 1, on Wednesday, **24 February 1960.** Dr K. Fink of Phoenix-Rheinrohr AG, Düsseldorf, presented a paper by himself, Dr W. Lueckerath, and Dr R. Flossman on *Fluoroscopy of steel blooms during the rolling process.*

NEW YEAR HONOURS 1960

Knight Bachelor Mr R. P. Morison, Q.C. (Independent Chairman, British Iron and Steel Federation)

C.B.E. Mr N. P. Newman (President, Joint Iron Council).

NEWS OF MEMBERS

Mr **R. Bartram** has resigned from the General Electric Co. Ltd on being appointed chief engineer to the Metallurgical Equipment Export Co. Ltd.

Mr **H. Bates** has joined Richard Thomas and Baldwins Ltd, Redbourn Section.

Mr **G. H. J. Bennett** has been awarded the degree of Ph.D. by Sheffield University, and has been appointed lecturer in the Department of Industrial Metallurgy at Birmingham University.

Mr **R. Betney,** who was recently elected an Associate of The Institution of Metallurgists, is now foundry metallurgist with British Insulated Callenders Cables Ltd, Prescot.

Mr **J. D. Bolckow** has been appointed a director of Redpath Brown and Co. Ltd.

Mr **N. R. R. Brooke** is now sole managing director of Guest, Keen and Nettlefolds (South Wales) Ltd, following the retirement of Mr K. S. Peacock, who remains chairman of the company.

Mr **D. Bruce-Gardner** has been appointed a director of Guest, Keen and Nettlefolds Ltd.

Dr **H. H. Burton,** C.B.E., has retired from the board of English Steel Corporation Ltd; he is continuing as research consultant to the group until the end of 1960.

Mr **Lewis Chapman,** C.B.E., has retired from the position of deputy chairman of the Birmingham Small Arms Co. Ltd; he remains on the board.

Professor **Morris Cohen** has been awarded the Francis J. Clamer Medal of the Franklin Institute.

Dr **T. E. Dancy** has been awarded the Robert W. Hunt Silver Medal by the American Institute of Mining, Metallurgical, and Petroleum Engineers.

Mr **R. T. Derricott** has been awarded the Diploma in Technology in metallurgy.

Dr **R. A. Dodd** is now associate professor of metallurgy at the University of Wisconsin.

Mr **Geoffrey Edwards** has resigned as managing director of Cardinal Steels Ltd and Gillott's Forge and Rolling Mills Ltd, but is retaining his seat on both boards.

Mr **P. Feltham** has been awarded the degree of D.Sc. by Leeds University.

Dr **A. T. Green,** C.B.E., retired from the position of director of the British Ceramic Research Association on 31 December 1959.

Mr **W. P. Hayton** is now control metallurgist (works) at the Workington Iron and Steel Company.

Mr **C. E. Holmstrom** has succeeded the Earl of Denbigh as chairman of John Bedford and Sons Ltd.

Mr **C. Hulme** has gone to Durgapur for three years as general technical superintendent.

Mr **A. Jollie** has been elected by the Court of Sheffield University to be a member of the University's Council.

Mr **E. T. Judge** has been appointed joint managing director of Dorman Long (Steel) Ltd; he has also been appointed an executive director of the parent company, Dorman, Long and Co. Ltd.

Mr **D. Kilby** is now melting shop manager at the Clydebridge works of Colvilles Ltd.

Mr **D. W. King** has left the Wellman Smith Owen Engineering Corporation Ltd to join the Incandescent Heat Co. Ltd.

Dr **R. F. Mehl** is on leave of absence from Carnegie Institute of Technology. He has opened an office in Zürich as a consultant to the United States Steel Corporation, and will provide a liaison between the corporation and those in Europe engaged in research on the scientific aspects of metallurgy.

Mr **T. R. Middleton** has been appointed a director of English Steel Corporation Ltd and director of research.

Mr **H. Morley** has been appointed a director of Shepcote Lane Rolling Mills Ltd.

Mr **J. S. Morton** has been appointed to the board of EFCO Ltd.

Mr **B. M. Müller** has relinquished the post of general works manager at the Mo i Rana plant of A/S Norsk Jernverk to become technical director at the company's Oslo office.

Professor **A. J. Murphy** has been elected a Fellow of the Royal Aeronautical Society.

Mr **J. Myers** has been elected an associate member of the Institute of Welding.

Mr **W. A. Nicol** has been appointed a director of John Lysaght Ltd.

Mr **E. A. Robinson** has been appointed chairman of Stein Atkinson Vickers Hydraulics Ltd.

Dr **V. B. Nileshwar** has left the research and development department of The United Steel Companies Ltd to take up an appointment as senior scientific officer at the National Metallurgical Laboratory of the Council of Scientific and Industrial Research at Jamshedpur, India.

Dr **J. G. Pearce,** C.B.E., has been appointed consultant to the Alloys Division of Union Carbide Ltd.

Mr **D. M. Rae** has returned from HM Dockyard, Malta G.C., to join the Admiralty Materials Laboratory, Holton Heath.

Dr **Carl H. Samans** has been elected a national trustee of the American Society for Metals.

Professor **A. J. Shaler** is on a year's sabbatical leave from Pennsylvania State University, and will be based in Belgium.

Mr **J. O. Taudevin** has been elected chairman of the Roll Makers Association of Great Britain.

Mr **D. Thacker** has been appointed head of the Department of Science at the Sheffield College of Technology.

Mr **W. B. Wallis,** president of the Lectromelt Furnace Division of the McGraw–Edison Company, is joining Strategic Materials Corporation as a consulting engineer to assist in the promotion of the Strategic–UDY process. Mr Wallis, who is 72, is an honorary member of the Electric Steel Makers' Guild in the UK.

Mr **C. N. Walters** has relinquished his appointment with British Oxygen Research and Development Ltd to become assistant technical adviser, iron and steel processes, with British Oxygen Gases Ltd.

Mr **H. W. A. Waring,** C.M.G., has been appointed a director of Guest, Keen and Nettlefolds Ltd.

Mr **C. H. T. Williams** has been appointed a director of the Steetley Co. Ltd.

Nr **N. Yarworth** has returned from the USA to join the Telegraph Construction and Maintenance Co. Ltd.

Obituary

Dr **Stewart J. Cort** (*elected* 1950), of Bethlehem, Pa., USA, on 23 September 1959.

Mr **Mark Douglas** (*elected* 1936,) of London on 27 December 1959.

Mr **James Alfred Peacock,** M.INST.C.E. (*elected* 1949), of Scunthorpe, on 30 October 1959.

Professor **Bradley Stoughton,** ENG.D., PH.B., B.S. (*elected* 1903), of Bethlehem, Pa., USA, on 30 December 1959.

Mr **Arthur Witherington** (*elected* 1936), of Birmingham, on 12 October 1959.

IRON AND STEEL ENGINEERS GROUP

Meeting on plate mills

A meeting of the Iron and Steel Engineers Group is being held at the offices of the Institute on Wednesday and Thursday, **6 and 7 April 1960.** The meeting will be devoted to the presentation and discussion of four papers on the design and operation of plate mills.

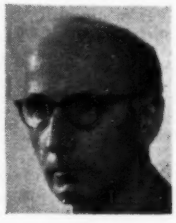
CONTRIBUTORS TO THE JOURNAL

N. W. H. Addink, PH.D.—Head, spectrochemical department, NV Philips Gloeilampenfabrieken, Eindhoven, Netherlands.

Dr Addink was born at Arnhem in 1905 and studied at Utrecht University under Professor Cohen. He was awarded the degree of Ph.D. in 1933 for work on the determination of densities of solids and interfacial liquid/solid tension. He joined Philips research laboratories in 1934, and worked on fluorescence and phosphorescence and on semiconductors. During World War II he was engaged on investigations into imperfections in crystals and the determination of the Avogadro number; since the war he has carried out work on emission spectroscopy and X-ray fluorescence analysis.

A. S. Appleton, B.ENG.(MET.), PH.D.—Lecturer, Department of Metallurgy, Liverpool University.

Arthur Stanley Appleton was born in 1934 and educated at Liverpool Collegiate School and Liverpool University, where he obtained the degrees of B.Eng.(Met.) in 1954 and Ph.D. in 1957. His postgraduate work was on the kinetics of graphitization in Fe–C and Fe–Co–C alloys. He went to the Department of Metallurgy at Massachusetts University of Technology in 1957 as a research associate, working on the effects of variables on the energy relations in the cold working and explosive loading of a Au–Ag alloy, returning to the UK to take up his present position in 1959.



N. W. H. Addink

T. Gladman

T. Gladman, M.MET.—Research student, Department of Metallurgy, Sheffield University.

Terence Gladman joined the staff of the Park Gate Iron and Steel Co. Ltd in 1950 as a technical staff trainee; in 1952 he joined the works metallurgical department, and transferred to the research department in 1956. As a result of part-time study, he obtained a Higher National Certificate in Metallurgy at Rotherham Technical College in 1955, and then went, sponsored by his company, to Sheffield University, where he obtained an Associateship in Metallurgy in 1956. This was followed by the degree of M.Met. for work on the effect of hydrogen on transformations in alloy steels in 1958. Since that time he has been working full-time at Sheffield University preparing a thesis for Ph.D.

G. F. Modlen, PH.D.—Department of Metallurgy, Sheffield University.

Geoffrey Frank Modlen was born in 1930 and educated at Haberdashers' Aske's School, Hampstead, and Queens' College, Cambridge. After graduating in metallurgy in 1953, he carried out research upon the behaviour of mild steel under fatigue, being awarded the degree of Ph.D. in 1958. He was appointed TI Research Fellow in 1957 in the Department of Metallurgy at Sheffield University, but resigned from this position in 1959. He is at present engaged on investigations into the fatigue strength of welds in structural steels.

G. F. Modlen

E. H. S. van Someren

E. H. S. van Someren, B.SC., F.INST.P., M.INST.W. —Research department, Murex Welding Processes Ltd (*author of paper in January issue*).

Ernest H. S. van Someren was educated in London and at Clifton, graduating from University College, London, in 1924. During ten years as an industrial chemist in the Midlands, he became a spectroscopist, and developed the metallurgical application of spectrographic analysis in laboratories in England, Denmark, and Norway. Since 1938 he has been concerned with analysis, non-destructive testing, photography, and welding.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Merger of information and development sections

Miss I. M. Slade, M.B.E., BISRA's information officer for many years, has relinquished that post to take on consulting duties in the Association's Operational Research Department at the Battersea Laboratories. She will be closely concerned with ergonomic studies, especially in connexion with problems involving safety and protective clothing, a field in which she has long been an authority.

Mr L. W. Stevens-Wilson, formerly head of the Development and Steel User Section, has therefore taken over new responsibilities. The distribution of information, the handling of enquiries, and the development and exploitation of the results of research, all of which are related, have been combined into a single unit. This will be known as Development and Information Services, with Mr Stevens-Wilson as its head.

Modernization of forges

The full proceedings of the conference on modernization of forges, organized by BISRA in September 1958, are now generally available.

Under the chairmanship of Mr F. J. Somers, the conference included the delivery of three papers: *Building a new forge* by A. C. Lowe, *Features that make for a well designed forge* by E. H. Kendall, and *A method for comparing alternative ways of forging* by J. Banbury, J. V. Chelsom, and D. H. Smellie.

The full text of the papers and a report of the discussion are included in the proceedings, which are available from the Information Distribution Officer, BISRA, 11 Park Lane, London W1, free to representatives of BISRA member firms, and 10*s* post free to non-members.

THE INSTITUTE OF METALS

Annual Dinner 1960

The Prime Minister (The Right Honourable Harold Macmillan, P.C., M.P.) has accepted an invitation to be the principal guest and speaker at the Annual Dinner of The Institute of Metals, which is to be held in the Great Room, Grosvenor House, Park Lane, London W1, on 31 March 1960. The United States Ambassador has accepted an invitation to reply to the toast of *The Guests*.

Solidification of alloys

At the invitation of the Institute's Metal Physics Committee, Dr W. C. Winegard, associate professor of metallurgy in the University of Toronto, lectured on *Solidification of alloys* on Wednesday, 10 February, at 17 Belgrave Square, London SW1.

Electron theory of metals

An educational session on *New aspects of the electron theory of metals* is being organized by the Institute's Metal Physics Committee. It will be held at the Hoare Memorial Hall, Church House, Great Smith Street, London SW1, at 2.30 pm on Wednesday, 30 March. There will be three brief lectures, each of which will be followed by discussion. The lectures are to be given by Dr W. M. Lomer (a general survey), Dr V. Heine (recent experimental work), and Dr J. Friedel (the electron structure of alloys). Visitors are welcomed; no tickets are required.

POWDER METALLURGY JOINT GROUP

Direct rolling processes

The next meeting of the Joint Group will consist of an informal discussion on *Direct rolling processes in powder metallurgy*, to be held in the Hoare Memorial Hall, Church House, Great Smith Street, London SW1, on Tuesday, 12 April. The programme is as follows:

10.30–12.30 Presentation and discussion of the papers:

1 Marshall: *Some mechanical requirements of plant for the roll compacting process*
2 Diebel, Thornburg, and Emley: *Continuous compaction by cyclic pressing*
3 Beddow and Forrester: *Continuous sintering of copper–lead to steel*

2.30–5 Presentation and discussion of the following papers:

4 Evans and Smith: *The compaction of metal powders by rolling. I. The properties of strip rolled from copper powders*
5 Evans and Smith: *The compaction of metal powders by rolling. II. An examination of the compaction process*
6 Worn and Perks: *Production of pure nickel strip by the direct rolling process*
7 Hunt and Eborall: *The rolling of copper strip from hydrogen-reduced and other powders*

(Papers 4, 5, and 6 were published in *Powder Metallurgy*, 1958, No.3; the remainder are due for publication in 1959, No.5)

5.30 Cocktail party in the Bishop Partridge Hall, Church House (tickets 12*s* 6*d* each).

Visitors are welcome; tickets of admission are not required.

Subscriptions

Subscriptions to *Powder Metallurgy* for 1960 are now due. The fee for members of The Iron and Steel Institute and The Institute of Metals is 10*s* per annum and that for non-members is 25*s*.

EDUCATION

Research fellowship at Oxford

Applications are invited for the Isaac Wolfson Research Fellowship in Metallurgy at St Edmund Hall, Oxford. Candidates, who should be suitable qualified graduates aged 24–35, may be either British subjects (from any Commonwealth country) or Israeli citizens. The appointment will date from 1 October and will be for three years. The Fellow will be expected to carry out research in a field approved by the Isaac Wolfson Professor. The stipend will be £800–1000 plus FSSU. The Fellow will be entitled to certain meals free of charge and either free accommodation in college or a housing allowance, and if resident abroad will be assisted in whole or in part with his travelling expenses.

Applications (in triplicate) should be sent to the Principal, St Edmund Hall, Oxford, on or before 23 April. Candidates should submit a detailed statement of career to date and of the research proposed, together with the names of two referees.

Research Fellowships at Sheffield

Graduates with research experience in metallurgy, solid-state physics, or physical chemistry who desire an opportunity to do metallurgical research on a subject of their choice are invited to apply for the following senior research fellowships tenable in the Department of Metallurgy: University Research Fellowship, J. H. Andrew Research Fellowship, Tube Investments Research Fellowship.

Normal tenure will be five years, but appointment will be for two years in the first instance and thereafter will be renewable annually. Starting salary will normally be within the range £800–1000 per annum, depending upon qualifications and experience, and there will be annual increments of £50 per annum. There will be superannuation provision under the FSSU. A higher salary will be paid to a candidate with exceptional qualifications.

Applications (three copies), including the names and addresses of referees, should reach the Registrar (from whom further particulars can be obtained) not later than 31 March 1960.

CORRIGENDUM

In the paper *Factors affecting fuming in open-hearth furnaces* by C. Holden (*JISI*, 1959, vol.193, Oct., 93–102), there is a mistake on p.96; line 21 in the right-hand column should read: 'leaving the chimney stack dropped from 460 to 80 lb/h.'

DIARY

1 Feb. CLEVELAND INSTITUTION OF ENGINEERS—*The new basic Bessemer plant at the Abbey Works of the Steel Company of Wales Ltd*, by C. E. H. Morris—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 pm.

2 Feb. SHEFFIELD METALLURGICAL ASSOCIATION—*Carbide precipitation during the tempering of alloy steels*, by Professor R. W. K. Honeycombe—BISRA, Hoyle Street, Sheffield, 7 pm.

3 Feb. SWANSEA AND DISTRICT METALLURGICAL SOCIETY—*Metallurgical facts and theories*, by Dr C. S. Ball—Central Library, Swansea, 6.45 pm.

8 Feb. LINCOLNSHIRE IRON AND STEEL INSTITUTE—*Special steel production*, by F. C. Martin—North Lindsey Technical College, Scunthorpe, 7.30 pm.

9 Feb. SHEFFIELD METALLURGICAL ASSOCIATION (Refractories Group) and REFRACTORIES ASSOCIATION OF GREAT BRITAIN—*Liaison between research and industry*, by H. M. Richardson—BISRA, Hoyle St., Sheffield, 7.30 pm.

9 Feb. SOCIETY OF CHEMICAL INDUSTRY—5th Chance Memorial Lecture: *The development of Siemens furnaces for glass melting*, by Dr W. M. Hampton—Lecture Theatre, Chemistry Department, University of Birmingham, 7 pm.

10 Feb. INSTITUTE OF METALS—*Solidification of alloys*, by Professor W. C. Winegard—17 Belgrave Square, London SW1, 6.30 pm.

10 Feb. MANCHESTER METALLURGICAL SOCIETY—*The precipitation-hardening stainless steels*, by J. I. Morley—Central Library, Manchester, 6.30 pm.

10 Feb. NORTH WALES METALLURGICAL SOCIETY—*Prospects for the continuous casting of tonnage steel*, by J. Savage—Flintshire Technical College, Connah's Quay, 7 pm.

11 Feb. LIVERPOOL METALLURGICAL SOCIETY—*Recent researches in the corrosion and protection of iron and steel*, by Dr J. C. Hudson—College of Technology, Liverpool, 7.30 pm.

15–18 Feb. NATIONAL METALLURGICAL LABORATORY—Symposium on *Pilot plants in metallurgical research and development*—Jamshedpur, India.

15 Feb. SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—*The conversion of a heavy forge to oil-firing and the development of a large oil-type furnace*, by D. D Carrington—Engineering Lecture Theatre, St George's Square, Sheffield, 7.30 pm.

16 Feb. NEWPORT AND DISTRICT METALLURGICAL SOCIETY—*Some aspects of gases in metals*, by G. E. Speight—Whitehead Institute, Newport, 7 pm.

16 Feb. SHEFFIELD METALLURGICAL ASSOCIATION—*Recent developments in magnetic materials*, by J. E. Gould—BISRA, Hoyle Street, Sheffield, 7 pm.

17 Feb. INSTITUTE OF PETROLEUM—Annual Dinner—Grosvenor House, Park Lane, London W1.

17 Feb. SOCIETY FOR ANALYTICAL CHEMISTRY (Corrosion Group)—*Adsorption on electrodes and its relation to rates of electrode processes*, by R. Parsons—14 Belgrave Square, London SW1, 6 pm.

18 Feb. EBBW VALE METALLURGICAL SOCIETY and THE IRON AND STEEL INSTITUTE (Iron and Steel Engineers Group)—*Modern steel pipes*, by Dr. J. S. Blair—RTB Lecture Rooms, Ebbw Vale, 7.15 pm.

18 Feb. STAFFORDSHIRE IRON AND STEEL INSTITUTE—*Prospects for the continuous casting of tonnage steel*, by J. Savage—Station Hotel, Dudley, 7.30 pm.

19 Feb. WEST OF SCOTLAND IRON AND STEEL INSTITUTE—*Application of electron microscopy in steel research*, by F. B. Pickering—39 Elmbank Crescent, Glasgow, 6.45 pm.

22–26 Feb. ENGINEERING MATERIALS AND DESIGN EXHIBITION—Earl's Court London.

23 Feb. SHEFFIELD METALLURGICAL ASSOCIATION (Methods of Analysis Group)—*The importance and determination of trace elements in steel*, by L. Kidman—BISRA, Hoyle Street, Sheffield, 7 pm.

24 Feb. MANCHESTER METALLURGICAL SOCIETY—*The presentation of metallurgical information*, by Dr J. W. Jenkin—Central Library, Manchester, 6.30 pm.

1 Mar. SHEFFIELD METALLURGICAL ASSOCIATION and SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—*Cold forging and extrusion of steel*, by Dr J. B. Hawkyard and N. S. Angus—BISRA, Hoyle Street, Sheffield, 7 pm.

2 Mar. BRITISH NUCLEAR ENERGY CONFERENCE—Informal discussion on education and training in nuclear power development—Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1, 6 pm.

2 Mar. SWANSEA AND DISTRICT METALLURGICAL SOCIETY—*Alternatives to the open-hearth process*, by Dr A. J. Kesterton—Central Library Swansea, 6.45 pm.

3 Mar. LIVERPOOL METALLURGICAL SOCIETY—*Semi-conductors*, by R. P. Chasmar—Department of Metallurgy, Liverpool University, 7 pm.

5 Mar. LIVERPOOL METALLURGICAL SOCIETY—Annual conversazione—University Club, Liverpool.

7 Mar. CLEVELAND INSTITUTION OF ENGINEERS—*An aspect of nuclear energy applied to power stations*, by F. Carr—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 pm.

7 Mar. SHEFFIELD METALLURGICAL ASSOCIATION and INSTITUTE OF BRITISH FOUNDRYMEN (Sheffield Branch)—*Bonding clays: recent work and ideas*, by Professor A. L. Roberts—Sheffield College of Commerce and Technology, Pond Street, Sheffield, 7 pm.

8 Mar. SHEFFIELD METALLURGICAL ASSOCIATION—Biennial dinner.

9 Mar. MANCHESTER METALLURGICAL SOCIETY—*Metallurgical aspects of fuel elements for nuclear reactors*, by Dr H. M. Finniston—Central Library, Manchester, 6.30 pm.

9 Mar. NORTH WALES METALLURGICAL SOCIETY—*The physical chemistry of steelmaking*, by Dr J. Pearson—Flintshire Technical College, Connah's Quay, 7 pm.

14 Mar. LINCOLNSHIRE IRON AND STEEL INSTITUTE—Annual General Meeting—North Lindsey Technical College, Scunthorpe, 7.30 pm.

14 Mar. SHEFFIELD METALLURGICAL ASSOCIATION and SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Symposium on *Hot extrusion of steel*.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 104 of the January 1960 issue of the *Journal*:

PHILIBERT, J., and CRUSSARD, C. The Electronic-probe microanalyser. Price reduced to 5*s*. [**1353**

Metal flow in forging. (VI) High temperature compression tests of metals.
AWANO, T., and OCHIAI, M., *Rep. Gov. Ind. Res. Inst. Nagoya*, 1957, Sept., pp.469–472. (£9) [**1418**

Metal flow in forging. (V) Some mechanical properties of plasticine.
AWANO, T., and OCHIAI, M., *Rep. Gov. Ind. Res. Inst. Nagoya*, 1957, Jan., pp.10–17. (£9 5*s*. 0*d*.) [**1419**

The effect of the degree of stabilization on the precipitation processes in austenitic chromium–nickel and chromium–nickel–molybdenum steels containing niobium.
BUNGARDT, K., *et al.*, *Arch. Eisenhütt.*, 1959, July, pp.429–434. (£4 10*s*. 0*d*.) [**1438**

Measuring the dust content in industrial gases and in the air–measurements of dust on the ground.
GUTHMANN, K., *Stahl u. Eisen.*, 1959, Aug. 6, pp.1129–1141. (£7) [**1440**

Lamination defects in rimming steel slabs. [From Chinese.]
SHAO, HSIANG-HUA, *Acta Metallurgica Sinica*, 1959, March, pp.16–21. (£8 15*s*. 0*d*.) [**1445**

Damage to tooth faces and the load capacity of rolling mill gears.
UNTERBERGER, M., *Stahl u. Eisen.*, 1959, Sept. 3, pp.1268–1272. (£4 10*s*. 0*d*.) [**1452**

Quantitative investigation of dendritic segregation in some iron alloys.
PHILIBERT, J., and BEAULIEU, C. DE, *Rev. Mét.*, 1959, Feb., pp.171–178. (£4) [**1454**

On the heat-treatment of austenitic manganese steels.
FREMUNT, P., and LORENC, A., *Slévárenství* (Prague), 1959, Aug., pp.309–316. (£6 10*s*. 0*d*.) [**1472**

Reactivity of various cokes.
KÜNTSCHER, W., *et al.*, *Neue Hütte*, 1955, Oct., pp.6–10. (£4 5*s*. 0*d*.) [**1474**

Evaluating the life of cold rolls
FUNKE, P. Sr., and FUNKE, P. Jr., *Stahl u. Eisen.*, 1959, Oct. 1, pp.1412–1419. (£5 15*s*. 0*d*.) [**1478**

Study of wall deformation during the hot reducing of tubes.
KOLMOGOROV, V. L., and GLEIBERG, A. Z., *Stal'*, Rolling and Tube Manufacture Suppl., 1959, pp.171–179. (£3 5*s*. 0*d*.) [**1481**

The physico-chemical properties of the structural constituents of coal. X. Autoxidation and chemical constitution.
KRÖGER, C., and BÜRGER, H., *Brennstoff-Chemie.*, 1959, March 18, pp.76–85. (£7) [**1484**

The detection of defects by ultrasonic testing.
KRAINER, H., and KRAINER, E., *Schweiss-technik*, 1958, March, pp.28–32. (£4) [**1486**

Wall thickness calculation of steam boilers and pressure vessels.
VEREINIGUNG DER TECHNISCHEN ÜBERWACHUNGS-VEREINE, *Brennstoff-Wärme-Kraft*, 1951, Dec., pp.422–426. (£2 10*s*. 0*d*.) [**1488**

Longitudinal seam welding of large-diameter pipes by high-frequency resistance heating.
GLUKHANOV, N. P., *et al.*, *Svarochnoe Proizv.*, 1959, Feb., pp.6–8. (£2 10*s*. 0*d*.) [**1489**

Reducing welded tubes in a three-roll stretch reducing mill.
GULYAEV, G. I., *et al.*, *Stal'*, Rolling and Tube Manufacture Suppl., 1959, pp.180–187. (£3 5*s*. 0*d*.) [**1491**

The development of the Maerz Boelens furnace.
BARTU, F., Brochure from Maerz Ofenbau AG, Zürich 1959, June. (£7) [**1497**

Segregation and heat-resisting behaviour.
KLEMM, H., *Metall.*, 1959, (8), pp.752–759. (£6 10*s*. 0*d*.) [**1498**

Increasing the life of mandrels for cold tube-reducing mills.
KOROBOCHKIN, I. YU., *et. al*, *Stal'*, Rolling and Tube Manufacture, Suppl., 1959, pp.151–159. (£3 5*s*. 0*d*.) [**1499**

Development of the high quality seamless tubes manufacture for the exploitation of petroleum and for geological research.
PEJČOCH, O., and ČERVENY, J., *Hutnické Listy* (Prague), 1958, (1), pp.2–8. (£6 15*s*. 0*d*.) [**1504**

The surfacing of pilger rolls of rolling mills.
PEJČOCH, O., and KUZNIK, J., *Hutnické Listy*, (Prague), 1959, (2), pp.173–184. (£10) [**1507**

Observations on foundry silicosis.
SCHMID, H. J., *Z. für Unfallmedizin u. Berufskrankheiten*, 1958, Sept., pp.221–231. (£3 5*s*. 0*d*.) [**1517**

Roll pass design for the manufacture of special-section welded tubes.
KRICHEVSKII, E. M., *Stal'*, Rolling and Tube Manufacture Suppl., 1959, pp.160–170. (£3 15*s*. 0*d*.) [**1521**

Removal of oxygen and moisture from argon, nitrogen, and hydrogen in the laboratory.
PFAFF, W., and HOFFMANN, K., *Arch. Eisenhütt.*, 1959, Sept., pp.539–540. (£1 5*s*. 0*d*.) [**1522**

The influence of the kinetics of the coke combustion process on the dimensions of the oxidation zone in a blast furnace.
OSTROUKHOV, M. YA., *Izvest. Akad. Nauk SSSR, Otd. Tekh. Nauk*, 1958, (6), pp.3–6. (£3 15*s*. 0*d*.) [**1526**

Development and present state of the problem of the introduction of an automatic coupling into the European standard-gauge railway systems.
ROHDE, W., *Eisenbahn-Technische Rundschau*, 1959, (4), pp.163–169. (£1) [**1534**

ABSTRACTS OF CURRENT LITERATURE *Iron and Steel Manufacture and Related Subjects* AND BOOK NOTICES

CONTENTS

Note: The letters *a*, *b*, and *c* refer to the three columns on the page concerned.

	PAGE
ORES—MINING AND TREATMENT	253*a*
FUEL—PREPARATION, PROPERTIES AND USES	253*c*
AIR POLLUTION AND SMOKE	254*a*
TEMPERATURE MEASUREMENT AND CONTROL	254*a*
REFRACTORY MATERIALS	254*a*
IRON AND STEEL, GENERAL	254*b*
BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON	254*b*
DIRECT PROCESSES	255*b*
PRODUCTION OF STEEL	255*b*
PRODUCTION OF FERRO-ALLOYS	257*c*
FOUNDRY PRACTICE	258*a*
VACUUM METALLURGY	261*c*
HEAT-TREATMENT AND HEAT-TREATMENT FURNACES	262*a*
FORGING, STAMPING, DRAWING AND PRESSING	263*a*
ROLLING MILL PRACTICE	264*a*
MACHINERY FOR IRON AND STEEL PLANT	265*b*
WELDING AND FLAME-CUTTING	265*c*
MACHINING AND MACHINABILITY	267*a*
CLEANING AND PICKLING	267*b*
PROTECTIVE COATINGS	268*a*
CLAD SHEET AND HARD-FACING	269*c*
POWDER METALLURGY	269*c*
FERRITES, CERMETS, AND CARBIDES	270*a*
PROPERTIES AND TESTS	270*a*
METALLOGRAPHY	278*a*
CORROSION	281*b*
ANALYSIS	284*c*
INDUSTRIAL USES AND APPLICATIONS	285*c*
HISTORICAL	286*a*
ECONOMICS AND STATISTICS	286*b*
MISCELLANEOUS	286*c*
BOOK NOTICES	287*a*

* Abstracts, the reference to which is marked with an asterisk are, or are to be made available as translations.

ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

ORES—MINING AND TREATMENT

Minerals for India's expanded Tata steel output J. Grindrod (*Min. J.*, 1959, **252,** May 15, 526–527) An account of the sources of ore, coal, Mn, and refractories, with map.

Technical and economic considerations concerning the use of manganese ores at the Gh. Gheorghiu Dej Metallurgical Combine S. Popa and N. Chindler (*Met. Constr. Masini*, 1959, **11,** (3), 222–227) The most rational use of indigenous Mn ores presents an important problem when highest productivity has to be attained with a minimum of coke consumption. Homogenizing the ores with the highest Mn content is the answer. Methods of obtaining this object are outlined.

Roasting reactions of chalcopyrite L. Meunier and H. Vanderpoorten (*ATB Métallurgie*, 1956, **1,** (2), 31–34) A piece of chalcopyrite was heated in a stream of air so that oxidation was confined to the surface; the core was unaltered and was surrounded by a layer of bornite enclosed in a layer of porous oxides, consisting mainly of Fe_2O_3. The mechanism of oxide formation is examined (11 refs).

Fundamental study of the dry decopperising process for pyrite cinders. II. On the pressure drops in fluidized roasting of pyrite cinders K. Okajima, M. Inouye, and K. Sano (*Tetsu to Hagane*, 1959, **45,** June, 595–600) Results of fluidization tests are reported for beds of pyrites cinder in the size ranges 100–150, 200–250, and 65–250 (four mixed fractions) mesh. Pressure drop–air velocity characteristics were reproducible up to the temp. range 950–1050°C: here abrupt changes occurred and fluidization ceased.—K.E.J.

Ore handling at a Virginian port J. Grindrod (*Min. Mag.*, 1959, **100,** May, 273–275) An account of the equipment at Newport Mews.

Raw materials handling at Ravenscraig Steelworks (*Mech. Handling*, 1959, **46,** May, 250–260) An account of the installations for the handling of coke, limestone, and ore and for the sinter plant and melting shop, with diagrams and illustrations.

Designing ore-treatment pilot plants R. D. Macdonald and F. M. Stephens jun. (*Min. Eng.*, 1959, **11,** May, 509–512) Factors in design, including such things as location, instrumentation, and costs are set out in general terms.

Briquetting of iron ore with basic additives W. Petersen and S. Wawroschek (*Stahl Eisen*, 1959, **79,** Sept., 17 1334–1344) The authors review the various processes for briquetting of fines and flue dust, and discuss the requirements made on the quality of the briquettes. They describe the operation of the various methods and processes in detail with special emphasis of the binders used. They conclude their report with a suggestion for a new process in which $Ca(OH)_2$ is used as a binder and stress the advantages that a basic conditioner carries.—T.G.

Mechanisms of iron ore sintering A. Maquestian (*ATB Métallurgie*, 1958, **1,** (5), 149–159) The pelletizing process, on a Dwight–Lloyd type grate or in a rotary kiln is discussed, the properties and composition of the sinters obtained are reviewed, and the present state of knowledge of various sintering processes is outlined with reference to the literature (23 refs).

The agglomeration of iron ores in Poland Z. Krotkiewski (*Hutnik*, 1958, **25,** (11–12), 467–470) An experimental agglomeration plant is described with detailed descriptions of the mixer plant, the agglomerating drum and the shaft-type agglomerating kiln, and the method of operation. The plant is in operation at Czestochowa with a daily output of 20–25 tonnes.—M.T.

Reducibility and softening temperature tests as a basis for assessment of iron ores A. Ofiok, S. Zielinsky, and A. Sulek (*Hutnik*, 1958, **25,** (11–12), 456–463) The apparatus for, and method of conducting, the reducibility tests are described. Experiments were conducted at 500, 700, 900, and 1100°C and changes in the condition of Krivoi Rog, siderite, and highly aluminous ores were recorded. The Krivoi Rog siliceous ore was the easiest to reduce, then the siderite ore, and lastly the siliceous ore. The two latter have wide softening temperature ranges and are not suitable for charging into blast furnaces in their raw state. They should therefore be roasted to restrict the softening temperature range and generally improve their properties before smelting in a blast furnace.

Arsenic, copper and other oligo-elements in ores, iron and steel C. Rekar and C. Crussard (*Rev. Mét.*, 1959, **56,** June, 23–29) A report on the conference held at Portoroz, Jugoslavia, in 1958 on the influence of impurities, mainly As and Cu in iron ores, on the properties of cast iron and steel, and methods of eliminating them.

FUELS—PREPARATION, PROPERTIES, AND USES

Report on the activities of the Marienau experimental station in 1957 R. Loison and P. Foch (*Rev. Ind. Min.*, 1959, **41,** April, 277–312) Activities described include an investigation of coal blending, additions of coke breeze and semicoke, size distribution of coal, preheating of coking charge, and experiments in coking in a fluidized bed.

Coal petrology and coal rank: observations in relation to carbonization G. W. Fenton and A. H. V. Smith (*Gas World*, 1959, **149,** May 2, 81–87) An extensive review with an account of test oven experiments of a preliminary nature.

Effect of reduced ring structures on the coking power of coals L. D. Ahuja, K. A. Kini, and A. Lahiri (*J. Sci. Ind. Res.*, 1959, **18B,** May, 216–217) Quinine sulphate and cholesterol improved coking quality.

X-Ray investigations of cokes and coals: On the structure of blast-furnace cokes A. M. Zubko and E. Z. Spekto (*Problemy Metallovedeniya i Fiziki Metallov*, (Moscow 1955) *AEC-tr*–2924, 1957, 32–38) The change in structure in passing from charge hole to bosh and then to tap hole is followed. The original lattice structure is retained to near the tuyeres where graphitization sets in. At the tap hole large perfect graphite crystals are present. The changes are not the same as those observed under laboratory conditions *in vacuo* where graphitization requires higher temperatures.

The effect of impact modulus on the granulometry of the fines of gas coals and on the properties and strength of cokes made from them H. Schranz (*Inst. Nac. Carbon Bol. Inf.*, 1959, **8,** Jan.–Feb., 1–14) German work on the effect of pulverizing on the coking properties of small coal is reported. Mill settings for maximum coke strength are established.

The production, properties and utilization of foundry coke F. W. G. White (*Castings*, 1959, **5,** May, 13) (A report of a symposium at Sydney, N.S.W. in March 1959). Opening remarks. **The effect of prolonged storage on the carbonising properties of N.S.W. high-volatile coals** H. R. Brown, P. L. Waters, and A. Watts (13, 15) Weathering tests for 3½ years are described. A slow progressive deterioration was

observed, greater with smaller coals. **Thermochemical properties of metallurgical coke** P. A. Scukin (15) Russian work is described suggesting a relation between cold and blast-furnace temperature strengths. It was pointed out that other work appeared to show that there was no such relationship. **High-carbon coke in theory and practice** A. Dahlmann (15, 17) The value of an anthracite-coal-petroleum by-product mixture (Densite) as a coke substitute is discussed and advantages are claimed. **General discussion** (17, 19, 21). **Changes in the porous structure of cokes and chars during gasification** A. Cameron and W. O. Stacey (39) Effects of drop tests and conventional handling producing breakage along the bedding planes and the segregations of minerals resulting are reported **General Discussion** (41–42). **Production of metallurgical coke from high-volatile coals of the Northern coalfield, N.S.W.** H. R. Brown, P. L. Waters, and A. Watts (42–43, discussion 43–44) Production of four types of coke is described.

Evaluation of drum tests to characterise coke strength A. Dahme (*Glückauf*, 1959, **95,** May 23, 680–687) The drum test was carried out at 100, 600, or 800 revolutions and measurements taken at intervals of 100 revolutions and graphed. In this way the structural strength of the coke, the proportion of pieces greater than 40 mm and the cleavage strength were determined.

AIR POLLUTION AND SMOKE

The measurement of smoke emission R. Jackson (*Steam Eng.*, 1959, **28,** Mar., 187–192) A review of methods including the Ringelmann chart and obscuration type meters. Precision is discussed.

Dust-content determination of industrial gases and the atmosphere and estimation of the dust deposits on the ground K. Guthmann (*Stahl Eisen*, 1959, **79,** Aug. 6, 1129–1141) Methods of dust-content measurement and the apparatus available are reviewed.—T.G.

TEMPERATURE MEASUREMENT AND CONTROL

Measurement, regulation and recording of temperatures (*Trattamenti Termici*, 1958, **1,** Nov.–Dec., 22–25) [In Italian] This first article in the series describes with the aid of diagrams the use of thermoelectric pyrometers. **Part II** (1959, **2,** Jan.–Feb., 22–25) The second article describes the choice of the galvanometer for thermocouples. **Part III** (March–April, 20–22) This article describes the characteristics and advantages of the potentiometer in connexion with thermocouples.

Continuous measurement of pig iron temperature (*J. d'Inf. Tech. Indus. Fonderie*, 1959, (105), May, 11–12) The use of an immersion pyrometer for measuring cupola iron temperatures in the runner is described, and suitable protective sheaths are discussed.

REFRACTORY MATERIALS

Development of Finnish production of refractory bricks and tiles O. Koponen (*Tek. Kemian*, 1959, **16,** March 31, 173–174) The development of the refractory industry in Finland, dating mainly from 1934, is described, with reference to the three principal manufacturers. Home production now satisfies 80% of Finnish firebrick requirements.

Some equipment for ceramic research F. H. Aldred and A. E. S. White (*Trans. Brit. Ceram. Soc.*, 1959, **58,** April, 199–223) Furnaces and apparatus for the measurement of creep are described and approximate diagrams of the Gd_2O_3–Al_2O_3 and Sm_2O_3–Al_2O_3 systems are obtained as examples and creep in compression of firebricks and in transverse bending of zircon–chrome compositions are given and tests for rising temperature refractoriness under load are discussed.

A new metallurgical weapon: silicon nitride (*Union Carbide, Alloys and Metals Review*, 1959, May, 2–3) Refractory properties and uses are noted.

Properties of improved phosphate-stabilised refractory materials made from Canadian Kyanite concentrate V. D. Svikis (*Amer. Ceram. Soc. Bull.*, 1959, **38,** May, 264–268) Additions of 20–30% calcined Al_2O_3 improved the properties and 2–4% H_3PO_4 maintained high density and stability when fired to 1700°C.

The thermal conductivity, thermal expansion and reactivity of blast furnace carbon bricks E. Mazanek and J. Janowski (*Hutnik*, 1958, **25,** (11–12), 447–456) Experiments were conducted to determine these properties of fired bricks and the contraction of unfired carbon bricks for use in blast furnaces, as well as the resistance of such materials to chemical attack in the presence of CO_2 and CO_2+N_2, based on their loss in weight at 1200°C. The experiments show the good properties of carbon materials for blast-furnace linings, especially in view of their high thermal conductivity.—M.T.

Production of casting pit refractories (*Metallurgia*, 1959, **59,** May, 245–246) A description of the opening of the new tunnel kiln at the works of Marshall & Co. (Loxley) Ltd. Sheffield, with an account of its design and equipment.

IRON AND STEEL, GENERAL

A present-day review of the manufacture of iron and steel throughout the world A. G. Lefebvre (*Rev. Soc. Roy. Belge Ing. et Indust.*, 1959, April, 157–202) The author first examines the main technical and scientific aspects of iron and steelmaking, and discusses the progress made in blast furnace and steelmaking and rolling practice. He then considers the development of iron and steelmaking practice in various parts of the world, including the use of direct reduction processes, and concludes with an assessment of future tendencies. A number of tables and diagrams of post-war production and capacity are given.

Iron in the world and at home R. Durrer (*Nachr. Eisen-Bibl. Georg Fischer (AG)*, (16), 62–64) The world production of iron is considered in relation to supply and quality of ore available, and probable future consumption. Development of new methods – oxygen refining and direct processes – and the use of electrical energy are reviewed. (Summary of paper read at a meeting held in October 1958.)

The Soviet iron and steelmaking industry (*Mét. Constr. Méc.*, 1959, **91,** May, 351–352, 355, 357, 359) The expansion programme, and technical and human problems connected with the iron and steelmaking industry in the Soviet Union are discussed.

Max-Planck-Institut Für Eisenforschung (*Bericht Über Das Jahr*, 1958, pp 224) An account is given of the work carried out during 1958 by the Institute in its various laboratories, followed by a bibliography of reports appearing during the year in *Stahl und Eisen* and *Archiv für das Eisenhüttenwesen*.

Oxygen in the iron and steel industry J. L. Harrison (*Eng. Found.*, 1959, **24,** April, 110–114) A general account of the use of O_2 for iron and steelmaking.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Modern blast furnace construction in the light of historical development C. H. L. Schneider (*Demag Nachr.*, 1959, (155), 12–20) The development of the blast furnace into its present form is traced, a number of illustrations of typical plant from various periods being given. Particular attention is paid to the evolution of shaft design.

New type of blast furnace A. Botha and L. Botha (*Lucrari Stiintifice, (Cluj)*, 1959, 343–352) [In Rumanian] It is shown by calculation that modern blast furnaces may be cooled under more favourable conditions both from the technical and economical points of view if a new construction and cooling system of the hearth, bosh, and stack is adopted. For medium capacity furnaces an alternative construction is suggested which limits the heat losses to below those of the normal furnaces. The refractory linings are reduced considerably. Output may be increased up to 50% because of the possibility of a higher heat load and the cooling water consumption is reduced to one-seventh of that for the normal furnace.

The effect of humid blast on the running of a blast furnace M. Folfasiński, (*Hutnik*, 1958, **25,** (11–12), 464–466) An outline of the thermal changes in the blast-furnace burden is given and the account illustrates the thermal reactions with examples from the practical working of blast furnaces and the phenomena which occur in the combustion zone. It is shown how the running of the furnace is regulated by changes in the humidity of the blast and its temperature. Optimum humidity is considered to be 20-g/m³. Further increases in the humidity do not step up the output of the furnace any further. Normally a constant level of humidity should be maintained with ±5·0 g/m³: when incomplete combustion or cooling of the furnace occurs, the situation may rapidly and effectively be brought under control by regulation of the input of steam within wide limits without undesirable effects of such changes on the high temperature zone of the shaft of a blast furnace.—M.T.

Ironmaking in Australia S. Klemantaski (*Iron Coal Trades Rev.*, 1959, **178,** May 22, 1195–1199) A description of the BHP installations based on a visit. Blast-furnace and sinter plant is briefly reviewed.

New Indian iron and steel plants. GHH equipment at Rourkela (*Iron Coal Trades Rev.*, 1959, **178,** May 1, 1109–1110) A brief account of the loading and other ancillary equipment of the 1000-t blast furnace is given.

Blast furnace Commission. 1st Part: General survey F. Paschal (*Centre Doc. Sidér. Circ.*, 1958, (5), 1019–1027) The author reviews the general layout and construction of blast furnaces used in Poland and Czechoslovakia. He reviews the nature of the charges and their preparation, the driving of the furnaces and gas cleaning. **2nd Part: Monographs** (1029–1047) The composition, layout, and method of agglomeration used in Poland and Czechoslovakia are discussed. This is followed by a description and comparison of the blast furnaces used, their construction, charging, and other characteristics.—R.P.

Automatic tuyere control developed for blast furnaces [B–I–F Industries Inc., Providence] (*Blast Furn. Steel Plant*, 1959, **47,** May, 484) A system for balancing the flow of blast air through blast-furnace tuyeres, developed by B–I–F Industries Inc., of Providence, is described.

Improving the operation of blast-furnace equipment I. L. Kordabmev (*Stal'*, 1959, (8), 684–687) The use of hot sinter and higher top pressures make greater demands on the charging equipment. Numerous improvements in details are mentioned. A three-bell installation is referred to.

The gaseous reduction of fine iron ores S. Y. M. Ezz and R. Wild (*JISI*, 1960, **194,** Feb., 211–222) [This issue].

Tap hole practice J. W. Carlson (*Blast Furn. Steel Plant*, 1959, **47,** May, 478–483) The improvements in blast furnace tap hole practice carried out at the works of the Colorado Steel Corp. are described, the advantages of a tar-clay tap hole mix being emphasized.

Use of 100% agglomerated ore in a blast furnace C. Rabaud, F. Douez, A. Damge, and Y. Gillet (*Centre Doc. Sidér. Circ.*, 1958, (9), 1879–1904) A series of tests was carried out at Dilling using 100% agglomerate. Performance and output figures were extensively analysed. It was found that neither efficiency nor output were diminished even though lesser quality coke was used.—A.M.A.M.

Operational trials with small coke 20–40 and ore 10–50 on blast furnace No.4 of the Société Cockerill-Ougrée at Seraing A. Firket (*Rev. Univ. Min.*, 1959, **15,** March, 140–153) Trials carried out in 1956 and 1958 on a furnace the effective height of which was 15 m, using small coke and ore of the above dimensions with an admixture of 30% sinter showed advantages, at least for a small blast furnace; these included lower throat temperature and diminution in the amount of dust formed, without loss of permeability.

Use of fine coke in the blast furnace C.-G. Thibaut (*Centre Doc. Sidér. Circ.*, 1958, (9), 1863–1877) Practical and theoretical aspects of the use of fine coke (25–80 mm) are discussed. Results of two sets of trials using fine coke are

recorded. Coke 10–30 mm diameter is at least as good as 30–70 mm and better than 70+ mm size. Cohesion and density of coke are concluded to be more important than granular size.—A. M. A. M.

Behaviour of a fluorine in blast furnace smelting III. Movement of Fluorine in a 1 cu.m. experimental blast furnace smelting Pao-tou iron ore Chow Jen, Chou Yuan-hsi, Hsu Yan-sun, Hu Cheng-ling, Mow Pai-ken, Wang Wei-yuan, Chow Sheng-hsiang, and Hsu Pao-ling (*Acta Met. Sin.*, 1959, **4,** March, 1–15) [In Chinese] The fluorine content of top gas depends on temp., and is low when the temp., is low; it exists mainly as HF. The reaction between gaseous HF and CaO or $CaCO_3$ in the charge closely approaches equilibrium. Of the fluorine entering the furnace, most enters the slag, some goes into the dust, and a little into the gas. It exists mainly as CaF_2 in the dust.

Pre-calculation of ore, limestone and coke requirements per tonne of pig iron, taking into account material and operational factors R. Görgen (*Arch. Eisenh.*, 1959, **30,** July, 381–390) Starting from the method of coke calculation proposed by Wesemann (*Stahl Eisen*, 1951, **71,** 873–877) a method of calculating ore, limestone, and coke requirements was developed, taking into account material analysis and the blast-furnace operation data to be anticipated. The complicated calculation was then simplified, and the method applied to four acid and basic Bessemer ores (10 refs).

Production in blast furnaces of a titanium-containing pig iron with aluminous slags N. Pilly (*Met. Constr. Masini*, 1959, **11,** (4), 273–280) The greatest degree of reduction of Ti in rutile was obtained by smelting a mixture of bauxite, steel chips, lime, and coke. The process is economical when besides titanium pig iron, aluminous slags are produced which may be used for cement or in the production of Al.

The low-shaft furnace at Ougrée as a small experimental blast furnace: Results of runs during 1958 E. Bonnaure (*Stahl Eisen*, 1959, **79,** Aug. 6, 1105–1119) The furnace erected in 1953 was used for a number of fundamental experiments during 1958, e.g. using higher top pressure at the same time varying the grain-size of the burden and the coke ratio. The effect of light-oil additions to the oxygen-enriched blast was studied. Gas and temperature were measured and the results used for a discussion of the mechanisms involved in blast-furnace processes with particular reference to the coke rate. The design characteristics for really large low-shaft furnaces are enumerated.—T. G.

Metallurgical treatment of ores of fine particle size in low-shaft furnaces H. J. Lux (*Hutnik*, 1958, **25,** (11–12), 432–440) In this article translated from German, the author from the Eisenwerk-West, Calbe, GDR, describes the development of low-shaft furnaces in East Germany, to handle Badeleben (16–27%Fe) Büchenberg (19–25%Fe), and Büchenberg brown coal ash (20–25%Fe). Problems of slag running, gas cleaning, particle grain size, etc. are discussed and comparisons made with conventional blast-furnace operation.—M. T.

The process of smelting pig iron in the low-shaft furnaces of Eisenwerk-West, Calbe, Eastern Germany W. Zolkowski (*Hutnik*, 1958, **25,** (11–12), 440–446) This article is a continuation of the preceding article and is based on two visits made by the writer in 1957 and 1958. Its contents are very similar. The low-shaft furnaces are reported to have an output of 100 t per 24 h from 22%Fe ore, and a battery of ten has been installed.—M. T.

A reply to the article of V. M. Shchedrin entitled 'A Certain Faulty Theory' W. Kuczewski (*Hutnik*, 1958, **25,** (11–12), 498–500) The author answers in detail the criticisms levelled against him in *Hutnik*, 1958, (10), 377–385 with reference to his method of calculation of the equilibrium constant of metallurgical reactions in particular in blast furnaces.—M. T.

Pig iron – an important raw material for steel J. K. L. Anderson (*Jernindustri*, 1959, **40,** March, 43–45) A brief outline of the composition and uses of pig iron is followed by a short reference to the iron producing plants in Norway.

Sponge iron by the HyL process F. W. Starratt (*J. Metals*, 1959, **11,** May, 315–318) The production and applications of sponge iron in Mexico by the HyL process are described. In this process, high-grade lump Fe ore is reduced in a retort by hot, reformed natural gas.

Equilibrium between sulphur in molten iron and H_2–H_2S gas mixtures A. Adachi and Z. Morita (*Osaka Univ., Fac. Eng. Techn. Rep.*, 1958, **8,** Oct., 385–394) Experiments are described in which the equilibrium relationship between S up to 5% in Fe and H_2–H_2S gas mixtures was re-established for the temperature range 1 550–1 750°C. It is shown that the activity coefficient of S in molten Fe decreases with increasing concentration (15 refs).

DIRECT PROCESSES

Direct reduction of iron ores. European progress A. Scortecci (*Rev. Tech. Luxembourg*, 1959, **51,** Jan.–Marcn, 6–33) The development and technical and economic aspects of direct reduction processes are outlined, and a description is given of the main features of these processes, with a diagram of each.

A review of direct-reduction ironmaking processes E. S. Paige (*Eng. Dig.*, 1959, **20,** May, 196–202) The reasons for seeking alternatives to the blast furnace are given and sponge-iron, shaft-furnace, fluidized-bed, and low-shaft and rotary furnaces are reviewed. Electric furnace methods and direct steel processes, especially the Cavanagh and Ontario Research Foundation jet-smelting processes are outlined with mention of the Flame-smelting (Cyclosteel) process.

Steel without coke P. Epron (*Rev. Mét.*, 1959, **56,** June, 3–11) The problem is discussed of overcoming the shortage of French coke in relation to the planned increases in iron and steel production, by economizing in coke consumption using conventional processes, by substituting natural gas and fuel from French-controlled sources, and by the use of electric and low-shaft furnaces and direct reduction processes.

New electric process for the direct reduction of iron ore A. de Sy, (*J. Four. Elect.*, 1959, **64,** March–April, 75–77) This deals with the subject matter of papers read by de Sy at the Autumn Meeting of the Société Française de Métallurgie, in 1958, and at an AIMME Conference in April 1959, which describe a direct reduction process in a two-chamber induction furnace in which carbon is dissolved in the bath in the first chamber, and decarburation or reduction of ore takes place in the second chamber. A refining rate of 4% C/hour is possible.

The HyL sponge-iron process (*Iron Coal Trades Rev.*, 1959, **178,** May 22, 1199) A brief note on the process as worked in Mexico.

Selective smelting of lateritic ores M. J. Udy and M. C. Udy (*J. Metals*, 1959, **11,** May, 311–314) The use of differential smelting by the Strategic–Udy direct process for obtaining from Ni and Cr-bearing iron ores ferro-Ni, ferro-Cr, and steel. The process can also be adapted for obtaining, for example, low-P steel plus high-P iron from a high-P ore.

PRODUCTION OF STEEL

From iron ore to steel sheet (*Gas World*, 1959, **149,** May 30, 1048–1049) An account of a visit to John Summers works at Shotton.

Brymbo Steel Works Ltd (*Met. Bull.*, 1959, May 12, supp.I–IV) The new Wrexham oxygen electric-process installation is described.

Investigation of the relationships between the controlled parameters and the effects of such controls during various periods of the open hearth melt V. N. Kornfel'd, A. O. Voitov, V. I. Koshelev, and L. S. Shteinberg (*Stal'*, 1959, (8), 755–763) A series of full-scale trials on the programming of furnace operation and of measured thermal conditions in various locations at various stages was made. The parameters suitable for control are considered and the most important factors are identified. A high degree of control was attained using O_2 in the scrap-ore process. The excess air coefficient is shown to be of considerable importance and susceptible to close control.

Investigations on silica bricks for open-hearth roofs) *Communauté Européenne du Charbon et de l'Acier, Haute Autorité*, 1958, (pp. 91) Recent progress in OH construction technique, including increased use of basic roof refractories is mentioned, and the object and scope of the trials to be described are outlined. These trials were carried out on four types of silica brick in 13 furnaces in various works in CECA countries. The results of the campaigns are given, and the influence of chemical composition and method of manufacture on the life of the bricks is analysed statistically.

Tests on silica roofs carried out by CECA J. Baron (*Centre Doc. Sidér. Circ.*, 1958, (5), 1071–1072) The following index of quality was arrived at after testing silica bricks: Equivalent porosity = true porosity + 20(Al_2O_3)—50 (absolute density – 2·30). The quality of bricks is higher the lower the index. Incompletely transformed bricks showed dimensional variation. Strict roof temperature control is necessary.—R. P.

Charging machine rail ties S. B. Leites (*Stal'*, 1959, (8), 207) Ties for securing charging machine rails to OH bay flooring are shown.

Nitrogen as an alloying element in manganese—vanadium structural steels produced in the open-hearth furnace H. J. Wiester, H. A. Vogels, and H. Ulmer (**Stahl Eisen*, 1959, **79,** Aug. 6, 1120–1129) From the mechanism of combining the N_2 with Al to form AlN finely dispersed in the matrix of the steels, it was concluded that V should have an even greater effect on ageing, etc. than Al, as higher N_2 (up to 0·025%) levels can be obtained. V additions up to 0·27% were used and the steels were in every respect superior to conventional OH steels even in their welding behaviour. The chemical analysis and mechanical test results as well as results of test weldments are reported.—T. G.

Influence of oxides of alkaline earth metals on the distribution between iron and iron slag L. A. Shvartsman, I. A. Tomilin, O. V. Travin, and I. A. Popov (*Problemy Metallovedeniya i Fiziki Metallov*, (Moscow 1955), *AEC-tr*–2924, 1957, 405–417) A tracer study was made by dissolving $Fe^{35}S$ in the iron by a method described and melting in 5 kg magnesite crucibles with technical iron and prepared slags. Effects of MgO, CaO, and BaO were observed and the reactions concerned are discussed. A temperature coefficient for the distribution function was found suggesting that equilibria are more favourable at low temperatures but that they are attained more slowly. Notes on dephosphorization are included. **Distribution of sulphur and phosphorus between iron and acid slag** I. A. Tomilin and L. A. Shvartsman (418–423) Coefficients were found to be lower than for iron slag but thermal effects of transfer to slag are somewhat increased and this is explained in terms of entropy change. A hypothesis of heat of solvation is advanced. **An investigation of the desulphurization of cast iron by soda** O. V. Travin and L. A. Shvartsman (424–432) Melts in graphite crucibles in an induction furnace were used. The efficiency of the process is shown to be greatly dependent on the S concentration and on temperature, increase of temperature decreases efficiency. Some soda tends to be lost by volatilization. The kinetics are those of a second-order process and the heat of activation was calculated. **A new method for studying equilibria in the system metal-slag** V. F. Surov, O. V. Travin, and L. S. Shvartsman (433–436) A laboratory tracer method is described in which molten slag is added in portions to metal until equilibrium is attained.

Slag removed with tractor shovels (*Mech. Handling*, 1959, **46,** May, 274) A note on the use of Allis–Chalmers equipment by the Great Lakes Steel Corp. for OH slag removal.

Electric or open-hearth furnace? G. Stassin (*J. Four Elect.*, 1959, **64,** 33–34; *Rev. Univ. Mines*, 1958, Dec., 596–601) A report on the performance of the 150-tonne electric arc Lectromelt furnace installed at Charleroi in 1956, and a discussion in which the economics of the furnace are compared with those of the OH furnace.

Contribution to the study of electric steel-works furnaces G. Grenier (*J. Four Elect.*, 1959, **64,** March–April, 81–85) This section

deals with types of resistance and induction melting furnaces, with reference to the possibility of their use for melting under vacuum.

The fluidized-bed electric reduction furnace W. Wenzel (*Stahl Eisen*, 1959, **79,** Aug. 20 1183–1186) The principles involved in this type of reduction furnace, in particular the fluidized bed and the application of electric resistance heating are described. A 200-kW furnace was constructed in Aachen; details of design and of the results obtained after a year's operation are briefly given. The advantages of this type of furnace are: Use of dusty or very fine ore, high output per volume, pre-reduction of the ore by the furnace gases resulting in substantial reduction in the power consumption.—T.G.

Report of the French Electrical Steel-plants Commission (Commission des Aciéries Electriques) (*Centre Doc. Sidér. Circ.*, 1958, (7), 1473–1477) The following were briefly discussed: (1) the introduction of certain alloying elements into electric furnaces and ladles by means of aluminothermal charges; (2) factors influencing the durability of roofs; (3) research into the improved use of arc furnaces; (4) behaviour of 'Söderberg' electrodes.—A.M.A.M.

Production of high grade steel by the electroslag remelting method I. P. Zabaluev (*Stal'*, 1959, (8), 715) Pilot plant studies are summarized.

Design and construction of the submerged arc furnaces W. M. Kelly (*J. Four Elect.*, 1959, **64,** (1), 27–32) A slightly abridged translation of an article from *Carbon and Graphite News*, **5,** (1) (National Carbon Co.) in which a rational design for this type of furnace is developed with regard to the 'k' factor, dimensions, and positioning of electrodes, and the diameters of the reaction zone and furnace vessel.

Improvements in the melting of ball bearing steel I. P. Zabaluev (*Stal'*, 1959, (8), 715) A note from Dneprospetsstal'. The refining period can be shortened with saving of electric power.

Metal stirring by induction in arc steelmaking furnaces M. G. Rezin, E. K. Kochnev, Ya. I. Drobinin, and N. S. Golubev (*Stal'*, 1959, (8), 713–714) The development of a circuit containing a step-down frequency changer is described and its advantages, over dynamo-electric types are set out. Defects of the Dneprospetsstal' design are noted.

Electromagnetic stirring of molten metal I. P. Zabaluev (*Stal'*, 1959, (8), 715) A note from Dneprospetsstal'. Trials are briefly summarized.

Purification of arc-furnace fumes L. Septier (*Centre Doc. Sidér. Circ.*, 1958, (7), 1479–1486) Two methods of fume collection are compared. Methods of dust removal by multi-cyclone separators, water scrubbers, dry filters, venturi scrubbers, and electrostatic filters are outlined. Special attention is paid to the problem of the fumes produced during O_2 injection. Consumption of water and electrical power is discussed.—A.M.A.M.

Improving the quality of 2Kh13 stainless steel for turbine blades I. P. Zabaluev (*Stal'*, 1959, (8), 715) A note from Dneprospetsstal'. Hair-line cracks are prevented by deoxidization with Ca–Si and Al. Al in the ladle produces the cleaner metal.

Reactor treated hot metal boosts output of steel (*Steel*, 1959, **144,** May 18, 118, 122) A unit claimed to increase OH output by up to 15% and that of electric furnaces by up to 50%, by S and Si removal is referred to. The process is continuous and centrifugal holding of the molten iron against the sides protects the refractory from the added alkali.

Ingot moulds, a critical survey K. G. Harris (*Brit. Found.*, 1959, **52,** May, 230–240) Square-type moulds up to 4 t and slab-type of 5–20 t are considered with regard to design, production, composition, and conditions of service consumption, and defects. Good design is shown to be a compromise between various requirements. The importance of carbon content and effects of Mn, S, Pb, and Cr are shown and various defects are correlated with conditions of use and cracking with a variety of factors.

Improving the process of ingot mould production N. V. Keis (*Stal'*, 1959, (8), 767) A note from Chelyabinsk. Reinforcement of mould tops with welded bands made from 76 mm × 9·5 mm plate and modification of the iron with 0·5 kg/t Mg increased mould life to some extent. A trial with cast-iron chills for the mould bottoms is to be made.

Reducing stoppages of open hearth furnaces for repairs V. F. Isupov (*Stal'*, 1959, (6), 525). A note from the Serov Combine. A new fettling method using scale is used.

Mechanization of the removal of slag from open hearth furnace pockets M. P. Sabiev, E. A. Ploshchenko, and B. P. Mikhno (*Stal'*, 1959, (6), 521–523) A metal box on wheels fits into the slag pocket and runs on rails. When cold the box is simply wheeled out and a spare freshly-lined box is put back. The gaps are filled with sand seals. The method of roof and other repairs is described. Heat losses are somewhat greater, 6·7% against 3–4% for fixed pockets. Slag is removed every 250–300 melts and box changing takes 12–18 h.

The nitrogen take-up of iron T. Kootz (**Stahl Eisen*, 1959, **79,** Feb. 5, 135–137) The author discusses the take-up of N in relation to the presence of O in iron. It was found that increased O contents in the iron do not lead to a noticeable reduction of the N level. Increased O content in the N-bearing gas affect the N take-up rate only slightly as long as the iron itself is low in O. The rate of N take-up is, however, directly related to the O content of the iron—T.G.

The pick-up of nitrogen during air refining G. Naeser and W. Scholz (**Stahl Eisen*, 1959, **79,** Feb. 5, 137–141) The problem of obtaining either nitrogen-low or nitrogen-rich steels was studied by refining iron with N–O mixtures. It was found that nitrogen take-up rate decreases with increasing O_2 content and – in the absence of O_2 – with increasing Fe_3O_4 content of the iron, but there was obviously no chemical reaction between N and Fe_3O_4. This is attributed to a reduction of the surface tension of the iron by the dissolved Fe_3O_4 that according to Gibbs' equation accumulates at the surface.—T.G.

Gases in steel made in hard driven large open hearth furnaces V. I. Yavoiskii (*Stal'*, 1955, (6), 506–513) The main factor in the degassing of steel produced with rapid melting in large OH furnaces working at high temperatures is the metal boil. An increase in the rate of carbon oxidation up to 0·7–0·9%/h in 185 t furnaces without the danger of cooling the bath by ore additions is always favourable for degassing the metal. The slag also plays an important part in degassing. With increasing basicity its viscosity rises and therefore the metal underneath a basic slag contains less hydrogen.

Degassing of steel by the circulation process H. Thielmann and H. Maas (*Stahl Eisen*, 1959, **79,** March 5, 276–282) The principles and application of the degassing of steel by circulation are described as well as an experimental plant that operates at a pressure of 2 mm. The reactions involved are described and the results – mainly with respect to H_2 elimination – obtained by treating various steels are compiled in a table. The advantages of the process are the high rates of reaction and easy control and adaption to changes in treatment time, vacuum, circulation, and gas injection.—T.G.

Testing chamber for the investigation of components of metallurgical furnaces Yu. I. Royengard and B. L. Poletaev (*Stal'*, 1959, (3), 287) A test-chamber for testing recuperators, burners, etc. is briefly described. It has a combustion chamber 150 × 280 × 240 cm and a working space separated by a partition 280 × 280 × 360 cm. Investigations carried out in it are indicated.

Investigations of melting in a Uniflow metallurgical furnace N. P. Zhetvin (*Stal'*, 1959, (5), 420) Modifications made to the design in 1958 are noted and the results of 154 heats are summarized. Ease of control is about equal to that of an OH furnace of the same capacity.

Scrap preheater cuts costs in electric-arc steelmaking R. J. Leary and W. A. Philbrook (*Iron Age*, 1959, **183,** Jan. 29, 90–93) The advantages expected from using preheated scrap in electric-arc furnaces are described. Experience with a trial preheating furnace is described. The following advantages are expected: fuel saving by preheating with gas (gas and electricity are thus used where their efficiency is greatest); greater availability of electric furnaces; better carbon control; safer.—D.L.C.P.

The development of large electric furnaces (*Stal'*, 1959, (4), 331–332) A review of the British and U.S. literature.

Fundamental investigation of bed linings of basic Héroult furnaces K. Deguchi and T. Nishimura (*Tetsu to Hagane*, 1958, **44,** Dec., 1354–1360) Chemical, polarizing microscope, and X-ray methods are used to determine the changes in the magnesia bricks caused by penetration of metal and slag and by corrosion when alloy steels and high-Cr alloy steels are melted.—K.E.J.

Rational design of short leads for arc furnaces Yu. E. Efroimovich, V. V. Timoshenko, and V. P. Tsukanov (*Stal'*, 1959, (5), 421–424) New leads of lower resistance and reduced reactance are described.

New methods to improve the production of steel A. M. Samarin (*Koh. Lapok*, 1959, **14,** Feb.–March, 49–54) The paper contains the lecture of Professor Samarin (USSR) given during the 1958 meeting of the Hungarian steelmakers in Diósgyör, Hungary. In the first part of the article the advantages of vacuum induction, and consumable electrode steel-melting techniques in Russia are discussed. The construction of some Russian equipment is described, and, for example, the properties of vacuum melted transformer, stainless, heat-resistant, and ball-bearing steels are given. The contamination of the melt by the crucible material in vacuum induction techniques can probably be diminished by using enamelled crucibles.—P.K.

An investigation of regulators and mechanisms for raising and lowering the electrodes of electric arc furnaces A. I. Sapko (*Stal'*, 1959, (6), 526–531) Measurements made on a 40-t electric furnace are described relating electrical parameters to the movements of the mechanical regulator mechanisms and these are interpreted. Various small improvements are suggested and a new system with electric control and hydraulic mechanism is tested. Reductions of play and time lag are important in all systems and rigid connections and reduced resistance to movement improve control. Further study of hydraulic systems is advocated.

An arc furnace with a tilting superstructure A. I. Sapko (*Stal'*, 1959, (4), 327–330) A tilting superstructure design is shown and described. It was devised for an 80-t furnace. Arrangements for rigid attachment of roof to superstructure are made.

Speeding up the melting of structural electric steel A. M. Levin, L. I. Teder, V. Ya. Monastyrskii, A. N. Glazov, V. A. Alyavadin, and A. D. Chernenko (*Stal'*, 1959, (4), 323–327) In trials at Kuznetsk, O_2 was used, the end of melting was combined with the beginning of oxidation, P was removed during melt-down, the C oxidized was reduced to 0·2%, deoxidation was stepped up by addition of coke and Fe–Si after working up the reducing slag, the metal being tapped with slag thoroughly mixed, desulphurization was accelerated and alloying speeded up by adding Fe–Cr at the beginning of the reducing period. Trial costs and steel quality are described. An increase of ~14% productivity was attained.

The use of bevelled ingot moulds for bottom pouring A. A. Lebed'kov and O. I. Yatsunskaya (*Stal'*, 1955, (6), 520–522) The ingot moulds are provided with a bevel round the top edge which causes the ingot, on cooling, to become suspended and to break off from the pouring gate. This shortens the time of stripping and cleaning of the ingots and of their further heat treatment.

The effect of the semi-permanent construction of moulds on the strength of the ingot mould E. Sh. Barskii (*Stal'*, 1955, (6), 553–558) The strength of square ingot moulds cast in semi-permanent forms depends to a large extent on the position of the joint of the casting box. The best position is diagonal, resulting in a two-fold increase in the service life of the ingot mould compared to with that of a mould with the joint along a face. Longitudinal cracks are the main cause for discarding the moulds

and hooping helps to eliminate the cracks. The efficiency of the hoops, however, also depends on the diagonal position of the casting joint.

The best shape for sheet-casting mould bottoms Yu. V. Zavershinskii (*Stal'*, 1959, (3), 226–228) A mould design with a tapered bottom part is described. The bottom is flat but the actual width is reduced by 50–60% by tapering at an angle of 17–21°. This reduces splashing on to the walls and curtaining, and rolling practice was modified to reduce scrap. Surface defects were also examined.

Graphite as a substitute ingot mould dressing N. V. Keis (*Stal'*, 1959, (6), 524) A research note from Chelyabinsk. **Use of unkilned magnesite teeming nozzles** (524) Wear was identical with that of normal nozzles but special trucks are needed for their transport to avoid damage to the edges.

Semi-permanent and single-use moulds for ingots N. I. Pavlovtseva (*Stal'*, 1959, (3), 275–281) Ingot moulds cast in semi-permanent moulds lasted 15–20% shorter than those cast in single-use moulds, developing transverse or reticular cracks, while the latter mainly failed by longitudinal cracking. Observations were made on over 2000 moulds for the origin of the cracks. Those from single-use frames formed cracks from the internal surface after 40–60 casts and those from permanent moulds from the outside after 20–30 casts. Conditions in casting and microstructures were examined and greater homogeneity was found in the single-use mould castings of hypoeutectic iron. Eutectic iron is recommended and a method of producing moulds in semi-permanent moulds equal to those from single-use moulds is given.

The advantages of moulds with wedge-shaped bottoms Yu. V. Zavershinskii (*Stal'*, 1959, (5), 413–417) The disadvantages of top-pouring are noted and the various types of mould used are noted. A design with a 56–60° wedge in the bottom is shown which minimizes scabs by the rapid formation of a 'cushion' of molten metal. Welding-on effects are discussed and the thermal conditions in the wedge-shaped portion are formulated. Scrap is also reduced by 7–8%.

A study of wall erosion in wide slab molds R. W. Joseph and L. J. Trilli (*AIMME Proc. O.H. Comm.*, 1958, **41,** 175–192) At Inland Steel Co., a characteristic of large slab moulds is the development of erosion pockets on the wide inner faces. The authors have observed the manner in which the erosion occurs and have related the degree of erosion with the surface quality of ingots, slabs, and cold-rolled sheets. Erosion less than 1 in. deep could not be related to slab and sheet defects, but when in excess of 2 in., laps and heavy slivers were noted.—G.F.

Lukens cement hot-drop practice R. L. Bunting Jun. (*AIMME Proc. O.H. Comm.*, 1958, **41,** 338–346) At Lukens Steel Co., the hot-tops used on slab ingots are made from a sand–cement mixture reinforced with ¼ in. wire and have been shown to have advantages in cost and yield when compared with conventional brick tops. The production of the cement hot-tops and their use in the casting pit are described.—G.F.

Recent developments in ingot-making processes S. Nishikiori (*Denki-Seiko*, 1959, **30,** Jan., 3–35) [In Japanese] A review, covering special steels, hot-topping, continuous casting, vacuum casting, bottom-pouring, etc. (28 refs.).—K.E.J.

Quality control of pouring aisle refractories C. L. Melov (*AIMME Proc. O.H. Comm.*, 1958, **41,** 320–323) The author emphasizes the value of careful control of quality of casting pit refractories. The system of inspection, sampling, and testing of refractories at Bethlehem Steel Co. is described.—G.F.

Effect of nozzle size on pouring rates and slab surface of rimming steels A. T. Peters (*AIMME Proc. O.H. Comm.*, 1958, **41,** 309–318) A series of full-scale experimental heats has been made at Inland Steel Co. to determine the variation of pouring rate with nozzle size and the resulting effect on rimming steel slab surface quality. Increasing the nozzle diameter from the standard 2 in. to 3 in. was found to be of advantage in pit operation and to result in improved surface quality of slabs and finished cold-rolled sheets.—G.F.

Effect of nozzle characteristics on steel pouring streams R. E. Stoll and E. C. Rudolphy (*AIMME Proc. O.H. Comm.*, 1958, **41,** 296–309) By means of model studies followed by full production evaluation, the authors have determined the effects of nozzle design, material, and refractoriness, and of operating variables, on the shape and pattern of steel pouring streams and the resulting steel quality. Based on the results, nozzle standards, and pouring practices have been revised, with resultant improvements in pouring performance.—G.F.

Experience with the accelerated teeming of steel E. V. Verkhovtsev and S. P. Bakumenko (*Stal'*, 1959, (4), 314–317) Pouring 2–2½ times as fast as usual improves the structure of the ingot top. Corrugated moulds should be used to avoid cracking.

Substitutes for Lunkerite V. K. Yatsura (*Stal'*, 1959, (6), 525) Equal parts of OH slag and coke breeze for uphill casting of 6-t tube steel ingots was satisfactory when the metal surface was clean.

Selection of ingot mould bottom nozzles for uphill casting V. K. Yatsura (*Stal'*, 1959, (6), 525) A note from Zakavkazsk. Shapes for easier break-off of runners were tested.

Zlatoustovsk works experience with widened feeder heads V. F. Isupov (*Stal'*, 1959, (6), 525) A note. Rejects for lapping were reduced by making the head 30 mm wider (internally) than the mould top.

Study of the hydrodynamics of molten steel at tapping or teeming. II. Effect of the degree of nozzle opening and deformation on the jet condition Y. Koike and Y. Muto (*Tetsu to Hagane*, 1959, **45,** April, 404–409) Model tests show that nozzles tapered at the entrance and with a short parallel portion at the outlet have similar flow characteristics to long nozzles, when the nozzle is slightly opened by the stopper. Increase or decrease of nozzle diameter by erosion or deformation causes turbulent flow. The depth of penetration of liquid by the jet is mainly influenced by nozzle diameter.—K.E.J.

Ingotrol – A system for pouring ingots of uniform size automatically W. A. Black (*AIMME Proc. O.H. Comm.*, 1958, **41,** 206–209) The 'Ingotrol' is a device for providing uniformity of ingot weight by automatic pouring control, whilst eliminating the safety hazard of manual control. It combines a weighing device for measuring the weight of metal dispensed and an automatic ladle stopper mechanism (the 'Autopour'), interlinked by electric pre-set counters. 69% of ingots have averaged within ±1% of ordered weight, with maximum variation ±3%.—G.F.

Casting of steel ingots without cracks J. Lántzky (*Koh. Lapok*, 1959, **14,** Jan. 13–17; Feb.–March, 60–64) The author has investigated the effect of chemical composition, steelmaking, and casting techniques, heating in soaking pits, and hot working on the transverse cracking of steel ingots by blooming. High sulphur content above 0·05%, more than 0·3%Cu content, and low Mn:S ratio, radius on the corners greater than 1/10 of the cross-section, ratio of ingot height to width of cross-section above 3·5, high teeming temperature, and, especially, high teeming rate, and, finally, a too short heating time in the soaking pits increase the tendency for cracking, but a higher ratio of the perimeter to the area of the ingot cross-section decreases it. The optimum ratio of the ingot height to width of cross-section is 3·3·5, and the optimum ingot-mould temperature before teeming is 70°C.—P.K.

Gases in ferroalloys N. Christensen (*Tidsskr. Kjemi, Bergv. Met.*, 1959, **19,** (3), 57–61) It is shown that the amounts of O_2, N_2, and H_2 introduced into steel by ferroalloy additions are unimportant, except for some high-Cr and high-Mn steels. The H_2 contents of some Norwegian Fe–Si are discussed in detail, and methods of its determination assessed (17 refs).

Saving nickel in the production of stainless steel G. D. Rogoza, A. L. Golovchiner, A. M. Poti, and A. K. Zaiko (*Stal'*, 1955, (6), 560–561) It was established experimentally that for large ingots of stainless Cr–Ni steels the ratio Cr:Ni must be increased to 1·8–1·85. In order to effect savings of Ni, the Cr content must be reduced and maintained in the melt at a level of 17–18%. By means of the rapid magnetic method of analysis the content of the melt can be rapidly corrected and this renders possible an appreciable saving of Ni.

Alloying steel with nitrogen obtained from organic compounds M. Piños and M. Zezulova (*Hutnik*, 1959, **9,** (1), 2–3) The alloying of Cr–Ni, Cr–Ni–Mn, and Cr–Mn steels with N_2 to replace nickel partly, and alloying with traces of N_2 to obtain dispersions of, for example, AlN, to improve the yield-strength of steels, are discussed. The authors' experiments on the use of nitrogenous lime, consisting mainly of calcium cyanamide as alloying agent are described. With the Mn–Si steel studied the nitrogenous lime was found to be as effective as current nitrided ferro-alloys, the lime being, however, much cheaper. Alloying technology used with the 100 kg ingots is outlined.—P.F.

Manufacture and use of ingot moulds (Precis of an article) H. Sandor (*Met. Constr. Masini*, 1959, **11,** (4), 323–330; *Öntöde-Kohaszati-Lapok* 1958, (5–6) General advice concerning design, manufacture, and conditions of service for ingots, giving results of practical tests of the measures suggested which in some cases resulted in a service life of 145 castings.

The influence of lead on cast irons for ingot moulds J. Duflot and J.-C. Margerie (*Rev. Mét.*, 1959, **56,** June, 39–41) A letter. An examination of three methods for the determination of ~300 ppm, of Pb in cast iron showed their reproducibility to be good. Pb of the order of 0·03% was found to be well dispersed in a machine-moulded casting. Investigations of the structures of Pb-bearing cast irons confirmed the tendency of the Pb to produce a more pearlitic structure.

Electric arc heating of ingot feeder heads I. P. Zabaluev (*Stal'*, 1959, (8), 715) A method of heating all three groups of a cast at once has been developed.

Casting steel in an argon atmosphere I. P. Zabaluev (*Stal'*, 1959, (8), 715) A note from Dneprospetsstal'. High Cr and Ti steels gave cleaner surfaces and better macrostructure when poured in A.

Supervision of ingot handling by television (*Process Control Autom.*, 1959, **6,** May, 229) The Steel Co. of Wales rolling mill control of the ingot buggy and shuttle car system is briefly described.

Lamination defects in rimming steel slabs Shao Hsiang-hua (**Acta Met. Sin.*, 1959, **4,** March, 16–21) [In Chinese] Large lamination defects were caused by pockets of high-temp. gas, surrounded by heavily segregated metal and containing non-metallic inclusions at the surface. During rolling these failed to weld, and nearby pockets tended to unite. After shearing and exposure, they mostly welded on further rolling. Lower tapping and pouring temp. reduced their occurrence.—K.E.J.

Tears in killed steel ingots J. Chvojka (*Hutnik*, 1959, **9,** (5), 155–160) The primary causes of tear formation, and correct methods of counteracting it, are discussed.—P.F.

PRODUCTION OF FERRO-ALLOYS

Manufacture of ferroalloys – a general survey H. Hagerup-Jenssen (*Tidsskr. Kjemi Bergvesen*, 1959, **19,** March, 9–15) An outline of the main types and production methods of ferro-alloys is given, with special reference to electric smelting, and production statistics relating to Norway are given.

Exothermic ferro-alloys (*Union Carbide Alloy & Metal Review*, 1959, May, 10–11) Exothermic compositions for forming alloy steels in the ladle after pouring from the OH are discussed. Fe–Cr and Fe–Mn are available.

The theoretical and practical bases of the production of low-carbon ferro-chromium H. Zac and B. Paczula (*Hutnik*, 1958, **25,** (11–12), 481–486) A review of methods of production of ferro-chromium in Poland and abroad, and a description of experiments conducted at the Ferrous Metallurgy Institute in Gliwice, for single stage production of low-carbon ferro-chromium in an electric arc vacuum furnace (0·1 mm Mg). At a furnace temperature of 1300°C the final product had a C content of 0·02%C. At this low C content better heat-resisting steels can be produced and Ti additions can be increased. The furnace is charged with briquettes of a mixture of pulverized

high-carbon ferro-chromium, quartzite, and limestone. The carbon is oxidized by the quartzite and CO_2 is liberated to leave low C content and high Si content ferro-chromium.

New trends in the manufacture of high quality ferrochromium and metallic chromium I. Petrman (*Hutnik*, 1959, **9,** (5), 163–166) Present methods are surveyed, and methods of production likely to prevail in the near future are analysed.—P.F.

Preparation of the manganese ores of the Vatra Dornei-Jacobeni region for the production of high quality ferromanganese I. Ion and M. Sirbu (*Studii Cercetari Metalurgie*, 1959, (1), 83–97) These ores (oxides or carbonates) are poor ores containing 20–25%Mn; 9–12%Fe; 28–35%SiO_2; 0·2–0·3%P; and 0·0–0·3%S. By mechanical separation (magnetic or sedimentation) concentrates of 33–35%Mn are obtained. By roasting a manganous concentrate a content of 45–46%Mn is obtained. Similarly ferrous concentrates with 20–27% and 30–36%Mn are obtained. The former ore is suitable for producing high-quality ferromanganese.

Preparing a ferronickel powder by gaseous reduction H. vander Poorten (*ATB Métallurgie*, 1958, **1,** (6), 177–181) The reaction of H_2 with Ni ferrite–$NiFe_2O_4$ at elevated temperatures to give an alloy resembling Invar is studied. Reduction of the constituent oxides Fe_2O_3 and NiO as a mixture produces a mixture of Fe and Ni in the temperature range of 400–600°C which was examines. Reduction of $NiFe_2O_4$, on the other hand, produces an alloy as shown by X-ray diffraction studies. The importance of the part played by solid-state reactions between Fe and the ferrite is emphasized (12 refs).

FOUNDRY PRACTICE

An American looks at European foundries C. A. Sanders (*Found. Trade J.*, 1959, **106,** May 7, 525–533) An abstract of a report noting briefly the processes observed in a visit to Great Britain and Germany in particular.

Hungarian diary A. R. Parkes (*Found. Trade J.*, 1959, **106,** May 14, 569–573; May 21, 623–626) An account of a visit to the 1st Congress of Hungarian Foundrymen in Budapest. Brief accounts of foundries visited and some of the technical sessions are given.

Inoculation of gray cast iron R. A. Clark (*Foundry*, 1959, **87,** May, 100–106) Theories explaining the results of inoculating cast iron with Fe–Si and other alloys are outlined, and the technique of inoculation is described briefly.

On the ageing decay of the effect of inoculation K. Sato and H. Yamamoto (*Imono*, 1959, **31,** Jan., 20–25) [In Japanese] 100 kg of molten iron were inoculated with 0·25–0·30%CaSi, and the effect of time was examined. The depth of chill did not change for 30 min, but then increased. The increase in mechanical properties was lost after 15 min, and then decayed below the original value. No change in hardness occurred. The Meehanite graphite structure changed to the flaky structure and then to eutectic graphite.—K.E.J.

Dynamic loading – its effect on casting design J. B. Caine (*Foundry*, 1959, **87,** May, 92–95) A discussion with examples is given of the use of correct design to minimize stress concentrations in a variety of casting sections and junctions (23 refs).

Radioisotopes utilisation in the foundry industry M. Pobereskin and D. N. Sunderman (*Mod. Castings*, 1959, **35,** May, 69–74) Some problems, in the solution of which isotopes can be used are enumerated. These include measurement of metal wear, chemical and physical tracing, mixing rate determination and the measurement of thickness. Techniques used are reviewed in outline, a list of possible isotopes is given, and some probable future applications are indicated.

Ways for reducing rejects in foundries D. Barbulescu (*Met. Constr. Masini*, 1959, **11,** (4), 303–309) A general review of conditions is given and a number of measures suggested, including complete reorganization, which have given good results where applied.

Report of the Sub-Committee of the Water-cooled Cupola Refractory Committee. I (*Imono*, 1959, **31,** Jan., 48–53) [In Japanese]—K.E.J.

BCIRA experimental cupola (*Found. Trade J.*, 1959, **106,** May 28, 613–622) An account with plan and illustrations of the hot-blast installation just completed for experimental purposes.

Lining the cupola (*J. d'Inf. Tech. Indus. Fonderie*, 1959, (105), May, 4) A note, illustrated by a diagram, of the lining of a cupola with three different materials according to the zone, the fusion zone having a monolithic silica–alumina lining.

Measurement of the supply of air to the cupola (*J. d'Inf. Tech. Indus. Fonderie*, 1959, (105), May, 1–3) The continuous measurement of blast volume by means of a Venturi is described.

Some points of view on the consumption of cupola refractories J. Drachmann (*Gjuteriet*, 1959, **49,** (5), 131–132, 133, 135–136, 139–140, 143–144) An attempt is made to find a more accurate formula relating ganister consumption to iron production than the usual equation $A = A_0 + bM$. Statistical analyses of tests on two different ganisters used for patching in the same foundry, and on results from other foundries were carried out and are reported. It is shown that the problem is complicated and much more work must be done to assess it satisfactorily.

Effect of aerodynamic factors on cupola operation G. L. Shires (*Castings*, 1959, **5,** May, 21, 23) Trials with a Perspex model are reported (discussion, 25).

Modernization of the Radom foundries W. Rawa (*Prz. Odlew*, 1959, **9,** (4), 106–109) The work of modernization of a fifty-year-old foundry unfavourably sited was hampered by lack of money and yet it has been completed in less than a year. Lack of money prevented also the carrying out of the full mechanization programme.—F.T.L.

The new foundry plants of Sulzer, Oberwinterthur F. Eisermann (*Giesserei*, 1959, **46,** June 4, 336–345) The construction and equipment are described of the new foundry plant built by Gebrüder Sulzer for steel and grey iron castings, where an increase in productive capacity has been obtained without additional manpower. The article is illustrated by photographs and diagrams.

Graphical aids for the calculation of the cupola burden F. Hickel (*Giesserei*, 1959, **46,** May 21, 301–304) Based on previous recommendations, the author develops a new and simplified method for calculating two or three components, and shows how the method can be adopted to calculate four or more components.

Choice of cupola blowers (*J. d'Inf. Tech. Indus. Fonderie*, 1959, (102), 1–3) Factors influencing the supply of air to the cupola are enumerated and calculated.

Cupola botting materials and their relation to casting defects A. D. Morgan (*BCIRA J. Res. Dev.*, 1959, **7,** April, 638–643) An investigation has been made of twenty-six botting clay mixtures. Two mixtures are recommended, one for small cupolas and the other for larger cupolas with a longer interval between botting.—A.G.

The use of the hot-blast cupola furnace for various metallurgical purposes S. Tunder (*Koh. Lapok-Öntöde*, 1959, **10,** April, 108–111) The use of water-cooled, hot-blast cupola furnaces, without lining above the tuyere level is suggested for the production of the material of ingot moulds, radiators, big castings for engineering purposes, and nodular cast iron, as well as for the refining of pig iron for steel making. Below the tuyere level, the cupola is lined with carbon bricks. The melting is performed under a basic slag.—P.K.

The general scheme of a cupola with automatic direction and control of the melting process W. S. Mysowski (*Prz. Odlew.*, 1959, **9,** (4), 94–97) A Russian design of a cupola with automatic control of the melting process, using an inclined skip hoist and applying continuous control of temperature, and of the chemical composition of bath and waste gases is shown.—F.T.L.

Development trends of the cupola process Z. Tyszko (*Prz. Odlew.*, 1959, **9,** (5), 134–142) A discussion of the main methods and trends in the development and improvement of the cupola process held on the occasion of the twentieth anniversary of the death of J. Buzek, a well-known Polish foundryman.—F.T.L.

The hot blast cupola. A new and simple method of heat recuperation for heating the cupola blast G. Ulmer (*Fonderie*, 1957, July, 287–302) A description and theoretical discussion is given of a new type of recuperator developed by the Centre technique des Industries de la Fonderie, which permits preheating of the cupola blast to a temperature of 400°C.

Modern methods of intensification of the cupola process in the light of the work of G. Buzek C. Podrzucki (*Prz. Odlew.*, 1959, **9,** (5), 128–134) The main reasons for aiming at greater efficiency of the cupola process are to increase to yield and to raise the temperature of the metal. Buzek's basic formula for calculating the cupola yield has been adapted to calculate the yield obtainable by means either of increased blast, pre-heated or oxygenated, or by means of additional rows of tuyeres.

Studies of the melting process occurring in the cupola, with particular reference to slag quality and its effect on the quality of the cast iron I. Pavlík (*Slévárenství*, 1959, **7,** (3), 121–126) [In Czech] The effect of additions of limestone on the quality of slags and irons was studied in an experimental cupola of 6½ in. diameter, having a cooled melting zone, and utilizing blast preheated to 500°C. Limestone additions were found not to affect the quality of the iron either with the basic or acid melting process. Sodium and Ti compound additions were found to lead to an increase in the strength of the iron by up to 30%. The paper is a continuation of earlier work with this cupola (*ibid.*, 1959, **7,** (1), 33–40).—P.F.

Trials of the intensification of the cupola process by the method of periodic enrichment of the blast with oxygen J. Szopa (*Prz. Odlew.*, 1959, **9,** (5), 142–153) A critical review of the research done in the field of enriching the blast with oxygen is followed by a description of experimental blows in two cupolas, 500 and 900 mm in dia.; the blast contained 23 to 29% O_2 and was applied periodically in periods lasting 14 to 55 min in order to save oxygen.

The possibilities of utilisation of briquetted coke formed from electrical station coal for the converter process C. Kalata, C. Podrzucki, and R. Wozniacki (*Prz. Odlew.*, 1958, **8,** (10–11), 308–313) The shortage of coking coal throughout the world to produce good quality metallurgical coke necessitates the search for new fuel sources. Experiments were carried out to compare cupola operation with high grade coke, coke and briquettes (50%+50%), and briquettes alone. Good quality cast irons were produced. The C content rose and the S content fell with increasing use of briquettes.

A mains-frequency induction furnace E. Horoszko (*Prz. Odlew.*, 1959, **9,** (2), 41–45) The use of such furnaces for melting cast-iron is considered, and their basic operational principles are outlined. Their operation is compared with that of cupolas using hot and cold blast. The electrical system and layout of a twin crucible furnace made by Siemens Halske in Vienna is described as a typical example.

Efficiency and design of modern mains-frequency induction furnaces J. P. Rohn (*Z. Metallkunde*, 1959, **50,** May, 294–298) The mains-frequency induction furnace was mainly used for non-ferrous metals, but its use is now extended to the melting, superheating, and holding of iron. It is usually employed in duplexing with a cupola, the lower C limit is 1·2%. Power consumption varies between 450 and 480 kWh/t according to the C level of the iron. The power factor of 0·7–0·75 is relatively high as compared with that for most non-ferrous metals.—T.G.

Design and working of static frequency treblers for heating and melting of metals G. W. Seulen (*Z. Metallkunde*, 1959, **50,** May, 299–306) Higher frequencies than mains frequency permit a very much higher power input into a furnace of the same capacity, the main reason being the strong agitation of the melt at low frequencies. The author describes the principle of the 'multiductor' equipment that was

developed in Canada and that allows trebling the frequency by means of special transformers. Industrial application of this equipment is discussed including that for cast iron, plain, and high-alloy steels.—T.G.

The acid Héroult type electric furnace in the steel foundry M. Viallon (*Fonderie*, 1959, Feb., 57–62) The relative advantages of the side-blown acid converter and the acid electric furnace for the production of steel for small and medium castings are discussed, and the principal characteristics of the electric furnace are described in some detail.

Properties of grey cast iron (*Gjuteriet*, 1958, **48**, Dec., 185–190) An account is given of the properties of the five grey cast irons standardized in Sweden. (SIS series.)

The production of high-strength cast-iron M. Csiszar (*Koh. Lapok-Öntöde*, 1958, **9**, Dec., 265–274) The author reports the development and progress made in the production of high-strength cast iron in Hungary. The necessary conditions for obtaining high strength and pearlitic structure, such as high casting temperature, correct chemical composition, and suitable casting techniques, are given. Good properties have been obtained by means of alloying either with about 0·8%Cr, or with about 0·4%Ni and 0·2%Cr.—P.K.

Contribution to the question of the influence of the size of H.C. coke on the melting results in the cupola, and comparison with normal foundry coke W. Patterson and W. Weskamp (*Giess. Tech. Wiss.*, 1959, (24), April 1285–1305) A series of trials with high carbon coke are described, with the object of relating size grading to cupola output. It was found that output, iron temperature, and other factors are a function of coke size; maximum output is obtained with a size of 60/80 mm. At this size slag bulk was a minimum and basicity a maximum. Comparative tests with normal foundry coke showed that, other conditions being equal, higher outputs and iron temperatures were obtained with HC coke, the CO_2/CO ratios being equal (40 refs.).

New types of cupola fuels L. M. Marienbakh (*Lit. Proizv.*, 1959, (3), 3–4) Tests begun before the last war with an improved coke based on plentiful supplies of lean coke and anthracite with addition of 25–30% coal tar pitch have proved the good quality of this fuel, but the excessive pitch content reduced its use. An improvement was effected by replacing gas coal with lean coal and the possibility of using Ural anthracite with an addition of coal tar pitch was also demonstrated since it was possible to obtain a fuel with low reactivity. Briquets are now produced with these fuels which are used in increasing quantities.

The use of iron-coke as cupola fuel J. Ptáčník and V. Müller (*Hutník*, 1959, **9**, (1), 25–27) A series of preliminary experiments with the use of coke containing 9·38% metallic iron showed this fuel to be at least as good as foundry coke. The use of the iron-bearing fuel appears also to be economically advantageous, but this could not be established with certainty in view of the non-existence, at present, of a fixed wholesale price for iron-coke in Czechoslovakia.—P.F.

Cupola with central tuyere (*Stal'*, 1959, (4), 382) A design is shown with a hollow conical tuyere set into the bottom of a cupola which is raised or lowered by air pressure. This evens out air distribution, reduces coke rate and wear on refractories and raises metal temperature.

A new hot-blast cupola with direct recuperation of the heat of the flue gas G. Ulmer (*Fonderie*, 1958, June, 263–272) The principle and operation of a pilot-scale hot-blast cupola are described, in which a recuperation system with some novel features is used. Some advantages of hot-blast practice are discussed.

Oxygen in the cupola F. Danis (*Fonderie*, 1958, Feb., 79–86) Trials carried out on the oxygen enrichment of the cupola blast are described, and the results discussed, including economic aspects.

A new combined radiation-convection hot blast recuperater G. Wellensiek (*Giessereitechn.*, 1959, **46**, April 23, 236–238) The new design of recuperator described has concentric radiation and convection heating surfaces, is insensitive to overheating and can easily be cleaned.

Effect of melting practice in the induction furnace and of treatment of the melt on the properties of cast iron W. Patterson and B. Sigg (*Giess. Tech. Wiss.*, 1959, July, 1363–1383) The relation of melting practice in an acid induction furnace and of the inoculation and mechanical strength and other properties were studied on a number of irons. The experiments which are described in detail with many diagrams and tables showed that, inter alia, high superheating is advantageous, but pouring and inoculation temperatures should be kept as low as possible. However, it is not the pouring temperature itself, but a long holding time with slow cooling to the pouring temperature that improves the graphite and in turn the mechanical properties of the iron. Long holding after inoculation should be avoided as it is detrimental to the action of the foreign nuclei.—T.G.

Mains frequency or medium frequency furnaces for melting cast iron? D. Hartmann (*Elektrowärme*, 1959, **17**, April, 134–138) A discussion on the paper 'On the metallurgy of cast iron in the induction furnace', by B. Marincek (*ibid.*, 1958, **16**, Oct., 354) with a reply.

Some data on the structural strength of cast iron I. O. Tsypin (*Lit. Proizv.*, 1959, (3), 7–10) Because cast iron is used in ever increasing quantities in machine construction, efforts are ceaselessly made to improve its mechanical properties: u.t.s., yield strength, relative elongation, reduction of area and modulus of elasticity. Magnesium iron under static stresses gives a u.t.s. between 40–75 kg/mm² (for non-alloyed iron) and a yield strength of between 60 and 80% of its u.t.s. after heat treatment. The modulus of elasticity is correspondingly high.

Inoculation of cast iron by addition of liquid steel M. M. Turbovskii (*Lit. Proizv.*, 1959, (3), 4–7) For some months the 'Tashselmash' plant has produced high quality cast iron by liquid inoculation. The initial metal is grey cast iron and the inoculant liquid steel produced in a converter with side blowing. Full details of the operation with all relevant data are given.

Materials and techniques of green-sand moulding A. Töth (*Koh. Lapok-Öntöde*, 1959, **10**, Feb.–March, 78–83) The author reviews the materials and techniques of green-sand moulding in Hungary. The role of bentonite is discussed in detail. Bentonite binding should be used for castings weighing less than 500 kg, waterglass binding for castings 50–1000 kg, and cement moulding for castings above 1000 kg.—P.K.

Experiments on the casting and heat treatment of alloy cast iron N. Hajtó and F. Varga (*Koh. Lapok-Öntöde*, 1959, **10**, Feb.–March, 42–56) The authors describe Hungarian small scale experiments on casting and heat treatment of Mn, Al, Si, and Mg alloy cast iron.

The effect of moisture content in the sand mould on grey iron castings K. Kato and S. Kita (*Imono*, 1959, **31**, March. 194–202) [In Japanese] Molten iron is best cast when the mould has a moisture content of 4%, but the surface appearance is best with 8–9%. Mechanical properties are best with 2–4% moisture. With natural sand moulds, moisture contents should be high, up to 9%.—K.E.J.

Cement moulding with quick binding L. Kalman and O. Racz (*Koh. Lapok-Öntöde*, 1959, **10**, Feb.–March, 65–70) Hungarian cement moulding experiments with short binding time are described, and the advantages of the method used over other rapid binding methods, such as using self-drying oils, or CO_2-waterglass moulding are discussed.—P.K.

Some nickel–copper–chromium cast irons. Properties and applications G. Hénon (*Fonderie*, 1958, Jan., 3–18) After discussing the possibilities of replacing Ni in alloy cast irons by Mn or Cu, the author describes a series of experiments in the manufacture of white and grey irons containing varying amounts of Ni and Cu, other elements including Cr remaining roughly constant within each series. The structures and properties of the irons are discussed, and some applications described and illustrated.

Experiments for the clarification of the effect of inoculation of cast iron W. Patterson and E. von Gumpert (*Giess. Tech. Wiss.*, 1959, July, 1341–1361) From the results of the experiments which are described in detail and which were carried out on basic and acid cast irons of various degrees of saturation it is concluded that in the acid induction holding furnace the inoculation effect decays the faster the smaller the quantity of inoculant. In the basic furnace increasing the holding time leads, after decay of the primary inoculation effect, to an improvement of the graphite structure. The iron should be melted and cooled down slowly to the casting temperature before inoculation, i.e. inoculation temperatures should be as low as possible. It is thought that oxide nuclei are responsible for the inoculation effect (41 refs.).—T.G.

Structural strength of nodular cast iron S. V. Serensen and O. Yu. Kramarenko (*Vestnik Mashin*, 1959, (1), 75–84) Plasticity and resistance to failure of nodular cast iron depends on the base metal structure. In ferritic structures these properties are near those of ductile metals and in pearlitic structures near those of brittle metals. The structural non-uniformity in nodular cast iron is greater than in steel, the size effect in these cast irons has therefore a more pronounced influence. Resistance to fatigue is increased in nodular cast irons with a reduction in the dimensions of graphite inclusions. A comparison of the strength characteristics of these cast irons and structural steels under alternating and static loads shows them to be close together, especially in the region of the pearlite-ferrite structure.

The operation of a basic lined cupola furnace with cold blast and the melting processes in the furnace F. Varga (*Prz. Odlew.*, 1958, **7**, (10–11), 284–290) In this translated article the development of cupola furnaces is outlined, and the results are given of research into the life of basic linings and their economic assessment. Lining wear is less in larger cupolas, and better results were obtained from dolomite–magnesite linings than from magnesite. Basic linings, though higher in cost than acid linings, give higher ingot mould life. The effect of the quantity of flux added on the chemical analysis of the melts was also studied. 6% additions were found to be the optimum. Lower S contents of the melts were more reliably obtained in the basic lined furnace. Studies of the relationship between slag basicity and the degree of desulphurization showed that in large cupolas better desulphurization is obtained with low basicity.—M.T.

Briquettes – the cupola operator's salvation (*Union Carbide Alloy & Metals Review*, 1959, May, 8–9) Ferrosilicon briquettes with a protective refractory cement which prevents oxidation as well as ensuring the contact of finely divided material with the iron are shown. These enable steel scrap charges to be raised.

The non-uniformity of properties of cast irons melted in a smaller capacity cupola S. Yamaguchi (*Imono*, 1959, **31**, Feb., 121–129) [In Japanese].—K.E.J.

Linear programming applied to economic selection of materials for furnace charges G. I. Gartner (*Mod. Castings*, 1959, **35**, May, 112–118) The use of linear programming in determining purchase requirements of furnace charge materials is explained, with the solution of a typical problem. A geometrical explanation of the linear programming technique is given as an appendix.

Electric cast iron G. Zuliani (*J. Four Elect.*, 1959, **64**, (2), March–April, 77–80) The use of the electric furnace for the production of steel-making and foundry irons and alloy cast irons is described, and an account is given of the ladle refining with O_2 of irons in which low Si contents are required.

Mains frequency crucible type induction melting furnaces (*Wild-Barfield Heat-Treatment J.*, 1959, **7**, June, 10–14) Notes on the coreless furnace.

Iron–carbon cast materials A. Wittmoser (*VDIZ*, 1959, **101**, July 11, 817–823) Ferrous castings are classified according to their structure into four main groups – cast steel, malleable cast iron, cast iron, and alloy cast iron, with further sub-divisions (27 refs).

The effect of manganese on the contraction of grey cast irons L. Sofroni and C. Cosneanu (*Studii Cercetari Metalurgie*, 1959, (1), 21–32) The effect of Mn on structure, on the degree of graphitization, hardness, and free linear contractions of grey cast irons with a low content (0·15–0·18%) and a high content (0·50–0·55%) of P, which corresponds to the cast irons alloyed with Mn in current use has been studied. It has been shown that an increase in the Mn content results in a modification of the metallic base structure of the cast iron according to the pattern pearlite–martensite–austenite or a mixture of these structural constituents. The expansion grows initially for a Mn content of 8–10% up to 0·5% maximum, for irons with low P, and with 3–5%Mn for irons containing P. Pre-pearlitic contraction increases sharply, and the total contraction reaches 2·1–2·2% with a Mn content of 12–14%.

Research on grey cast iron with lamellar graphite. A study of the correlation of properties with dimensions A. de Sy and J. Van Eegham (*Comptes Rendus de Recherches, Travaux du Centre Belge d'Etudes et de Recherches en Fonderie*, 1959, (22), June, pp. 230) The physical properties are related to structure which depends upon rate of cooling which is governed by the size of the cast. Tensile strength, hardness, and bend tests were made on 63 casts and full details are given. Degree of eutectic saturation and the effects of P are assessed. Some special castings are described in a later section.

Automotive crankshafts cast in green sand (*Foundry*, 1959, **87,** May, 150–151) Central Foundry Div. of General Motors Corp. is producing automobile crankshafts in green sand; the advantages of this procedure over forging are outlined.

Spheroidal graphitic cast irons A. Gillet (*Arts et Manuf.*, 1959, (86), April, 31–34) The physical properties of nodular iron with a pearlitic, ferritic, or ferritic—pearlitic matrix are described, and a note on alloy nodular irons is given.

Results obtained with nodular cast iron A. Chisu (*Lucrari Stiintifice (Cluj)*, 1958, (1), 83–90) [In Rumanian] On the strength of experimental results it was found that s.g. cast iron bearings do not present greater risks than bronze bearings. The Rumanian State Railways have sanctioned their use and placed substantial orders.

On the various properties of nodular graphite cast steel M. Homma, H. Meguro, A. Minato, and Y. Abe (*Imono*, 1959, **31,** Jan., 9–19) [In Japanese] The properties of nodular graphite hypereutectoid cast steel containing <1·7%C are determined, including physical properties, impact value, fatigue limit, castability, magnetic properties, wear resistance, and hardenability. This material does not call for great care in selecting materials. Various superior properties make it suitable for thin-section castings, electrical applications, etc.—K.E.J.

Selected samples of the application of nodular cast iron H. Mühlberger (*VDIZ*, 1959, **101,** June, 707–708) An abstract of *VDI Berichte*, 1958, (27), 55–59 'Nodular Cast Iron – a New Structural Material' – one of ten papers on nodular iron contained in the issue of the 'Berichte'. Reference is made to the use of ductile iron for high-pressure gas mains, and boiler and gas producer parts.

Cylinder linings for Diesel engines of nodular cast iron A. Chisu (*Lucrari Stiintifice (Cluj)*, 1959, 381–386) [In Rumanian] The general conditions which must be satisfied by s.g. cast iron Diesel motor linings are given. It was experimentally established that these linings have a better service life and contribute to increasing the quality of the engines.

Study concerning the influence of microstructure and composition on the quality of piston rings of nodular cast iron T. Dumitrescu and P. Popescu (*Met. Constr. Masini*, 1959, **11,** (1), 18–28) It is possible, with centrifugal casting, to obtain piston rings with pearlitic structure containing 3·8%Si, and with a ferritic structure containing over 4·0%Si. Below 3·8%Si content the structure becomes pearlite–cementite. An increase in the Si content to between 4·0 and 5·2% has a favourable influence on elasticity, strength, and resistance to wear. P between 0·4 and 0·6% is necessary in all cases.

Crankshafts of nodular cast iron H. Mühlberger (*VDIZ*, 1959, **101,** June, 713–718) Crankshafts, although most economically made from castings, are normally forged from steel; they can now be made satisfactorily – particularly when hollow – by casting in nodular cast iron. Some examples are given (23 refs).

Carbon flotation in ductile iron A. H. Rauch, J. B. Peck, and G. F. Thomas (*Mod. Castings*, 1959, **35,** May, 61–64) Carbon flotation in the form of segregation of graphite nodules was found to occur during solidification of hypereutectic ductile iron castings, when the C equivalent (%T.C.+1/3 Si%) exceeded 4·55%.

Molding and pouring large steel castings H. Chappie (*Foundry*, 1959, **87,** May, 96–99) The importance of uniformity and consistency of properties in sand for steel casting is emphasized, and details of the system of selection and the properties of sands used by the National Supply Co., subsidiary of Armco Steel Corp., are given.

Dry steel casting at the 'Strungul' works C. Wanyorek (*Met. Constr. Masini*, 1959, **11,** (4), 320–322) A series of measures are described for drying the patterns with a methane flame which, as applied in the 'Strumgul' works, has reduced rejects to an average of 4·5% during the last year.

The scope and achievement of modern stainless steel casting processes (*Union Carbide Alloys & Metals Review*, 1959, May, 4–6) A note on precision castings from non-magnetic high strength steels and their uses.

Problems encountered in the production of large high-quality castings from heat-resisting austenitic steel C. A. Iodkovsky (*Hutnicke Aktuality*, 1958, **16,** 36–45) The development of a 15–15–3 Cr–Ni–Co steel, also containing Mo, W, and Ti, for use at high temp. in power plant is described. Casting technology and the introduction of new exothermic mixtures for risers are discussed. The steel can be made by the use of scrap; O_2 is employed in the steelmaking.—P.F.

Design and casting plan for steel castings T. Matuura (*Imono*, 1959, **31,** Jan., 41–47) [In Japanese] Design problems of castings complicated shape are reviewed.—K.E.J.

Some experiences in the manufacture of steel castings for high-pressure turbine components G. L. Hancock and J. Taylor (*Brit. Found.*, 1959, **52,** May, 246–254) Methods of casting are described and the uses of 0·5%Mo, 1%Mo–Cr, Mo–V, and 2–3%Cr steels with special reference to creep are discussed. The effect of Al additions is, in particular, reviewed, and improvement of creep properties and elimination of pin-holing can be attained. Alloy steels that might be introduced are mentioned and a section on methods of inspection is added.

Note on the use of spheroidal cast iron in the die casting of alloys of zinc and aluminium L. Oltrasi (*Fonderie*, 1959, Feb., 75–78) A discussion is given of the use of nodular cast irons in various parts of the moulding machines use in the die-casting of some Al and Zn alloys; results compare favourably with those made from iron with lamellar graphite.

Malleable cast iron R. Román Martínez (*Dyna*, 1959, **34,** June, 422–429) [In Spanish] An account of the history, properties, structure, methods of moulding, casting, and heat-treatment of malleable cast irons is given.

Restrike improves malleable castings in many ways R. B. Stubbs (*Steel*, 1959, **144,** Feb. 16, 152–154) The advantages of restriking malleable iron castings are explained. Lower costs, closer tolerance parts and fewer rejects result. Warping during annealing can be corrected and machining operations may be saved.—D.L.C.P.

Steel casting techniques made more precise V. F. Isupov (*Stal'*, 1959, (6), 525) A note from the Serov Combine. High metal temperature and rapid pouring caused cracking of ingot surfaces during the early rolling passes.

The casting of steel in moulds A. Heuvers (*VDIZ*, 1959, **101,** May 11, 561–567) It is pointed out that defects in steel castings can often be eliminated or diminished by co-operation between foundry engineer and designer. Factors in design and choice of materials are discussed.

The effect of small additions on structure non-uniformity and heat resistance of large castings of 12 Kh11V2NMF–L steel N. S. Kreshchanovskii, A. F. Silaev, and M. F. Sheshenev (*Lit. Proizv.*, 1959, (3), 39–42) Results of investigation have shown that small additions to the stainless steel of Ba (in the form of Al–Ba–Ca alloy) results in an appreciable increase in its mechanical properties, especially its heat resistance. Less effective are Ce (in the form of alloy) and Ca.

Hot top heating by means of briquettes and dressing to reduce discard N. P. Zhetvin (*Stal'*, 1959, (5), 419–420) A Fe-Si, fireclay and $NaNO_3$ mixture has been developed for hot topping and a briquette of coke breeze, charcoal, wood shavings, and $NaNO_3$ bound with sulphite liquor was later devised. Feeder head design is improved and exothermic sprinkling mixtures are formulated.

The use of lunkerite made from charcoal and coke breeze V. F. Isupov (*Stal'*, 1959, (6), 525) Defects occurred when coke breeze was substituted for charcoal.

A new sand plant O. Carlsson and S. Rydén (*Gjuteriet*, 1959, **49,** Feb., 41–42, 44, 46–48) The construction and operation of a new sand plant in Central Sweden are described.

Testing and properties of moulding sand F. Fischer (*Koh. Lapok-Öntöde*, 1959, **10,** Feb.–March, 56–64) The author describes the testing of moulding sands, and concludes that for attaining high permeability with adequate strength, optimum distribution of the grain size of the particles is necessary.—P.K.

Dust removal plants and dust separators for sand preparation plants and knock-out floors H.-W. Brandt (*Giesserei*, 1959, **46,** April 23, 228–233) Examples of dust-removing techniques and equipment are given, together with a description of the dust-removal system of a modern foundry.

The use of synthetic resin pattern plates – an important factor in the rationalization of foundry practice H. Maul (*Giesserei*, 1959, **46,** May 7, 275–279) The use of suitable synthetic resins in the manufacture of pattern plates has given satisfactory results with greatly reduced costs. Experience in the use of epoxide and polyacrylate resins is described.

Dimensionally accurate castings by the use of suitable patterns H. Radmann (*Giesserie*, 1959, **46,** March 26 164–168) By means of a number of examples and illustrations, it is shown how the pattern designer can improve the dimensional accuracy of sand castings.

Influencing the Brinell hardness and structure of slides in machine tool casting K. Wüllenweber (*Giesserei*, 1959, **46,** May 7, 265–274) After an outline of general considerations relating to the design of patterns for large machine castings, a series of experiments is described to investigate the influence of various mould and core sands on quenching properties, and the effect of casting in various wall thicknesses or structure. The effect of Si content on the proportion of ferrite in the structure is examined for test-pieces cast in permanent moulds.

Experiments with exothermic feeder heads I. Lipovetz and P. Németh (*Koh. Lapok-Öntöde*, 1959, **10,** Jan., 1–11) Small, medium, and large-scale experiments in Hungary with exothermic feeder heads on steel castings are described, and the economics considered.—P.K.

Magnesite risers H. Riess (*Giessereitechn.*, 1959, **5,** Jan., 25–26) The method of ramming magnesite risers is described and illustrated.

Contributions to the study of gating in the steel foundry. Verification of a simplified method of calculating gating, applied to the particular case of three wheel rims M. Jaumain (*Fonderie*, 1958, June, 273–278) The simplified method of calculation using open risers, proposed by Bishop, Myskowski and Pellini is applied to the design of the gating system of three wheel rims.

Determination of the feeder sections of castings poured in sand C. Trenclé (*Fonderie*,

1958, Jan., 25–36) In this section, speed factors are calculated for various methods of pouring, direct and indirect, tables are drawn up for the different methods, and some examples are worked out.

The comparative characteristics of materials for moulds V. V. Gusev (*Lit. Proizv.*, 1959, (3), 26–29) Investigations were carried out into the failure of cast iron at high temperatures under conditions nearest to the service of the moulds. The process of failure depends on the intensity of surface and intercrystalline oxidation and on the transformation structure causing corrosion and growth of the cast iron. The tests covered the comparative strength of various materials for moulds during contact with the liquid iron. It was found that nodular graphite inclusions, after a number of castings of liquid iron, change their form, assuming an elongated and laminated appearance. This phenomenon is due to thermal shock and needs further investigation.

Steel moulds for large steel castings S. I. Smolenskii, N. N. Guglin, G. F. Zasetskii, A. K. Provornyi, and V. A. Tyutev (*Lit. Proizv.*, 1959,, (3), 23–26) Experimental findings show that the optimum parameters ensuring the longest service life of moulds are: wall thickness 150–170 mm; a moderate number of small size strengthening edges or none at all, removable bottoms of small thickness; the metal of the mould should be a steel with a maximum of 0·10%C and a S content below 0·025%: tempering to remove internal stresses. (The latter operation must be further investigated.)

Technical and economic indices of casting into metallic moulds N. P. Dubinin (*Lit. Proizv.*, 1959, (3), 22–23) The introduction of metallic casting boxes in foundries cheapens production and increases by a small factor the usefulness of casting platforms without any additional expenditure. The cast moulds and metallic boxes can compete with conveyor belt production for castings in single-use boxes only with a large measure of mechanization and a high degree of organization.

Laboratory equipment for investigating casting and core mixtures V. I. Krylov (*Lit. Proizv.*, 1959, (3), 19–20) Descriptions with drawings are given of various sorts of laboratory apparatus for sampling, weighing, and separation of they clayey components of sand, for determining grain sizes, strength of mixtures, humidity, gas permeability, etc.

On the sources of sulphur diffusion into the surfaces of metallic moulds Yu. N. Litvakovskaya and Yu. P. Bardachev (*Lit. Proizv.*, 1959, (3), 29–30) The impregnation of the surfaces may be avoided by protecting them from sulphur diffusion during use, either by reducing the operating temperature, or by water cooling. Another method is to use protective coatings which form with S heat-resistant compounds, thus preventing its penetration into the metal.

Temperature stresses on the surfaces of metallic moulds O. Yu. Kotsyubinskii (*Lit. Proizv.*, 1959, (3), 30–34) A method is explained for determining the temperature stresses occurring on the surfaces of the metallic moulds and also the influence of other factors, and ways are suggested for raising the service life of the metallic casting boxes.

Pouring steel castings in permanent moulds R. Graichen (*Giessereitechn.*, 1959, **5**, May, 131–134) It is shown by examples that a changeover from sand to permanent mould casting in series production gave a marked improvement in quality and reduction in manufacturing costs.

The hot forming of moulding sand H. W. Dietert and T. E. Barlow (*Giesserei*, 1959, **46**, July 16, 421–424) A formula for determining hot deformation is given, experimental equipment for its measurement in sand described, and measures for increasing the amount of deformation at 1100°C enumerated.

Consideration of the calculating method for permeability with grain distribution of foundry sand K. Hashimoto and S. Kojima (*Imono*, 1959, **31**, Feb., 115–120) [In Japanese] Experimental results show that the permeability of beds of sand formed by layers of different but uniform sizes (coarse + fine, or coarse + medium + fine) can be calculated from given equations.—K.E.J.

Contraction of uniform-grain moulding sand K. Hirakata (*Imono*, 1959, **31**, Feb., 108–114) [In Japanese] The effects of bentonite content and uniformity of sand size on the parameters linking height of a sand specimen and amount of ramming are investigated.—K.E.J.

Improving the quality of castings by using sepcial mineral binders C. Wanvorek (*Met. Constr. Masini*, 1959, **11**, (3), 184–195) The raw materials are mixed with a cement prepared by calcining together at about 1450°C lime and clay and iron oxides in certain proportions. The resulting products are a combination of simple and complex Ca, Al, and Fe iron silicates the mineralogical composition of which is imperfectly known. In the presence of water this combination decomposes giving hydrated simple silicates and forming a colloidal gel. A small addition of alkalis (1–2%Na) shortens the time of binding.

Development of a technique for the semi-continuous casting of cast iron pipes N. F. Dubrov (*Stal'*, 1959, (8), 767) A note from the Urals Scientific Institute for Ferrous Metallurgy. Composition, temperatures, and times are given.

New technique for casting piercing points for tube rolling mills N. F. Dubrov (*Stal'*, 1959, (8), 767) A note from the Urals Scientific Institute for Ferrous Metallurgy. A continuous casting machine has been devized. It is not described.

A packaged mechanized foundry Rubery Owen & Co. (*Metalw. Prod.*, 1959, **103**, May 1, 765–770) A machine producing small sand castings moulds at 240/h and a complete set-up only 30 × 60 ft is described.

Infra-red radiation used in foundries for drying T. Steflea (*Met. Constr. Masini*, 1959, **11**, (3), 178–183) The process is explained and compared with other methods. The savings in time and electrical energy are indicated.

'Araldite' epoxy resins for foundry patterns (*CIBA Tech. Notes*, 195, 1959, May, 8) An illustrated account of suitable mixes and methods of fabrication.

The Shaw process O. Madono (*Imono*, 1959, **31**, Feb., 129–131) [In Japanese]—K.E.J.

Making precision castings for commercial applications P. I. Castings Ltd (*Machinery*, 1959, **94**, May 6, 1027–1034) The lost-wax method is described. Parts are illustrated and discussed.

The present position of permanent mould casting in the Soviet Union F. Naumann (*Giessereitech.*, 1959, **5**, May, 134–139) The post-war development of the process in Russia, examples of the wide variety of applications, and technical and economic data are given (11 refs).

Letter concerning two contributions on problems of permanent mould casting of grey iron F. Naumann (*Giessereitech.*, 1959, **5**, May, 139–141) Criticisms are made of two papers by Schwarz and Junghans (*ibid.*, 1959, **4**, (8), 225–233; (2), 35–46), which discussed the development of permanent mould technology.

The manufacture of spun soil and rainwater pipes E. Morgan and H. H. M. Milnes (*Brit. Found.*, 1959, **52**, May, 240–245) The development and operation of the Stanton-Wilson process are described.

The effect of the pouring rate, mould-hardness and numbers of gate for the scab in natural sand mould U. Harada, K. Nishiyama, and T. Kubota (*Imono*, 1959, **31**, Feb., 99–107) [In Japanese] The incidence of scab is more severe the longer the pouring lasts and the higher the mould hardness becomes.

A study of two defects in one casting (*J. d'Inf. Tech. Indus. Fonderie*, 1959, (105), May, 15–16) A permanent-mould casting in A-U5 GT alloy, heat treated in a salt bath at 490–500°C, followed by water quenching at 30°C, showed a defective wrinkled zone, with the appearance of brown oxidation stains after heat treatment. Microscopical examination of this zone showed the presence of microcavities. These were found to be due to the fall of metal in the feeder system, which was modified. The microcracks also led to the formation of the brown stains by allowing penetration of the salt.

Deoxidation defects in steel castings R. A. Flinn and L. H. Van Vlack (*Mod. Castings*, 1959, **35**, May, 93–97) The nature, origin, and suggested methods of elimination of non-metallic cope side defects in steel castings are discussed. In Al-deoxidized steel, inclusions contain the species corundum, surrounded by reaction products; it is shown that this corundum can only originate in the metal as a result of deoxidation with Al. Mechanical techniques and the use of complex deoxidants are suggested.

Porosity, inclusions and pinholes in malleable castings C. A. Sanders (*Mod. Castings*, 1959, **35**, May; 103–111) The causes of porosity in malleable castings are discussed with examples, and the presence of inclusions is shown to be a major factor. Hot sands are considered to be the main factor influencing pinhole porosity; the effect of melting practice is also discussed (74 refs).

Timing of expansion scab formation J. E. Haller (*Mod. Castings*, 1959, **35**, 65–68) A step casting was designed to promote buckling or scabbing. The results obtained indicated that one type of scab or buckling is caused by sand expansion, and occurs when the mould is filling or when the metal is still liquid.

Basic ventilation problems for foundries V. Drobota (*Met. Constr. Masini*, 1959, **11**, (4), 331–336) Based on health regulations which specify the permissible amount of solid suspensions of quartz, quartzite, asbestos, and other types, also of gases such as CO etc. minimum conditions are outlined. Russian references are cited.

Ventilating the shell mould foundry W. H. Puryear (*Foundry*, 1959, **87**, May, 88–91) Changes in ventilating equipment at the Lynchburg, Va., Foundry Co. due to developments in shell making equipment are described.

Foundry goggles Joint Advisory Committee (*Found. Trades J.*, 1959, **106**, May 21, 585–591) Second report is summarized. Proposed methods of testing are outlined, especially by impact. No glass lens withstood the impact test used, but several plastic lenses were satisfactory. Work on the ophthalmic properties of these has started.

VACUUM METALLURGY

Vacuum melting (*Iron Coal Trades Rev.*, 1959, **178**, June 5, 1300) A brief review of induction and consumable-arc furnace methods.

Fusion and casting of metals in a vacuum R. Brocard (*Usine Nouv.*, 1959, **15**, July 2, 99) A review of British processes and of induction and arc melting furnaces.

An investigation of 30 Kh GSNA steel vacuum treated in the ladle I. P. Zabaluev (*Stal'*, 1959, (8), 714) A note from Dneprospetsstal'. Effects of 9–10 min at 22 mm are noted. H_2 and hair-line cracks are reduced, also impact strength and resistance to crack propagation.

Modifications to the vacuum fusion method in the Eisenhüttenmännischen Institut Aachen K.-D. Unger, K.-G. Schmitz, K. H. Gerdom, and H. Schenck (*Arch. Eisenh.*, 1959, **30**, July, 411–414) The equipment, described and illustrated by a diagram, is suitable for working at temperatures up to at least 2000°C, with satisfactory control. Intensive water cooling of the quartz tube diminishes secondary reactions between the extracted gases and metal deposits Examples of the use of the equipment are given (17 refs).

On the fundamental study of high-temperature chemistry. IV. On the automatic vacuum recording controller for a furnace chamber T. Tomonari, M. Takahashi, S. Togawa, and H. Arakawa (*Bull. Fac. Eng. Yokohama Nat. Univ.*, 1959, **8**, March, 113–123) [In English] To cover the vacuum range from 10^{-6} to 10^{2} mm, the pressure transducer is one of three devices – a mercury U-tube manometer, a Pirani gauge, or an ionization gauge. The pressure recorder is an electronic recording potentiometer. The controller is an electronic deviation-recording potentiometric type with a pneumatic controlling unit having proportional plus reset plus rate actions.—K.E.J.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The future of heat treatment O. Schaaber (*Trattamenti Termici*, 1958, **1,** Sept.–Oct., 3–5, 23) [In Italian] A short account is given of future trends in heat treatment. Brief reference is made to the possibilities of research into changes in crystallographic structure of metals with the aid of radioactive isotopes and the electron microscope, to the study of fatigue, distortion, and precipitation, to the use of X-rays to determine internal stresses, to the increased use of automation devices to control the final product and to the development of controlled atmospheres.

Development of the low frequency channelled induction furnace P. Guesné (*J. Four Elect.*, 1959, **64,** March–April, 87–89) The development of these furnaces – with particular reference to Ajax furnaces is outlined. Two non-ferrous applications are given.

The various applications of controlled atmospheres O. E. Cullen (*Trattamenti Termici*, 1959, **2,** March–April, 3–10, 22) [In Italian] The advantages of gas carburizing, carbonitriding, recarburizing, and homogeneous case-hardening are described with the aid of diagrams.

Progress in the application of controlled atmospheres J. H. Evans (*Trattamenti Termici*, 1958, **1,** Nov.–Dec., 16–18) [In Italian] This is an account of equipment and methods used in gas carburizing and in heat treatment in controlled atmospheres in the United Kingdom roller bearing industry.

Controlled atmospheres. I. (*Trattamenti Termici*, 1958, **1,** Sept.–Oct., 15–18) [In Italian] A definition of the term 'controlled atmosphere' is given. The use of NH_3 and its derivatives is described with the aid of diagrams. **II.** (Nov.–Dec., 19–21) The second article in this series describes the advantages and disadvantages of using H_2 and N_2. **III.** (1959, **2,** Jan.–Feb., 19–21, 27) The third article in this series examines controlled atmospheres based on propane, methane, and coal gas with a variable volume of air. With the aid of diagrams the operation of exothermic generators is described. **IV.** (March–April, 17–19) The advantages of endothermic generators are described. Endothermic gas is increasingly used. Its cost is relatively low. Main applications are (1) hardening, annealing, and normalizing of medium and high carbon steels and high speed steels in controlled atmospheres without decarburizing or incrustation, (2) carburizing and carbonitriding, (3) brazing in continuous furnaces and, (4) sintering of non-ferrous and by special methods also of ferrous metallic powders.

Protective gases G. Kluge (*Draht*, 1959, **10,** June, 243–250) Various types of protective gases for heat treatment are described and classified, and a table is reproduced showing their properties and the grades of steel for which they are suitable.

Heat treatment and distortion of parts F. B. Heard (*Trattamenti Termici*, 1959, **2,** Jan.–Feb., 17–18) [In Italian] An account is given of the problems involved and methods employed in an Australian works producing parts for the automobile industry and particularly gear teeth to overcome strains and distortion during heat treatment.

Practical methods of limiting distortion during heat treatment G. Bidigare (*Trattamenti Termici*, 1959, **2,** March–April, 11–12) [In Italian] The article describes the conditions under which distortion and cracking occur during heat treatment and quenching and briefly lists the methods of limiting or avoiding such distortion.

The possibilities of reducing the costs of production by correct heat treatment W. T. Groves (*Trattamenti Termici*, 1959, **2,** Jan.–Feb., 3–6, 29) [In Italian] The writer describes the economies derived from using various methods – nitriding, cyaniding or carbonitriding, gas carburizing, and induction or flame hardening and concludes with a summary of the factors governing the choice of the steel to be used.

Electronic device simulates furnace heating problems P. M. Unterweiser (*Iron Age*, 1959, **183,** Feb. 12, 102–104) Services which can be rendered by Thermalog, a new temperature analogue simulator, are described. It can be used for specifying heat-treatments of all kinds and in design problems. An electrical model of the system is used; capacitors simulate heat capacity and resistors simulate thermal conductivity.—D.L.C.P.

Bright isothermal hardening of springs made of the steel 50 KhFA A. A. Zholdak (*Metallov. Obra. Met.*, 1959, (5), 57) Conditions for salt bath treatment are given. The wire is heated in KCl 2·5 min + 20 sec per mm dia to 860°C ± 30°C and cooled in NaOH + 5·8%Na_2CO_3 at 330 ± 50°C with intensive stirring for 20–30 min. If a yellow colour appears it is removed with $K_3Fe(CN)_6$. The springs are cooled in water at 60–80°C and passivated in 5%$NaNO_2$ for 10–15 min and dried at 100–150°C.

The design of wire hardening furnaces H. Junker (*Wire*, 1959, April, 52–54; *Draht*, 1959, **10,** May, 217–219) Design factors for wire-patenting furnaces are discussed, in relation to refractories, method of firing, and temperature control.

The practical application of gas carburizing by direct injection of alcoholic mixtures O. Liedholm and B. Lineberg (*Trattamenti Termici*, 1958, **1,** Nov.–Dec., 9–15) [In Italian] A detailed description with diagrams of the method used is given. It is concluded that the injection of only one fluid does not produce constant results in industrial production but that by using two different fluids one for carburizing and one for diffusion, constant results can be obtained without prolonging the period of heat treatment.

Carburising liquid iron with solid carburising agents R. Krzeszewski (*Giesserei*, 1959, **46,** July 16, 417–421) 0·1%C steel melts with Si contents from 0·6–3·6% were carburized at 1480–1520°C by the immersion of graphite tubes. An equation is derived which describes the carburizing process with sufficient accuracy, and the applicability of the equation is shown by comparisons with results obtained from the literature (11 refs).

Heat treatment of sintered iron I. Ljungberg and P. U. Gummeson (*Prec. Met. Mold.*, 1959, **17,** April, 30–31, 58) Pack carburization experiments were made at 910°C and hardness was measured. The effects of copper on electrolytic iron powder compacts are tabulated. Various other factors are correlated with hardness.

Fundamental study of high frequency surface hardening S. Ishida, J. Sakai, and T. Taniuki (*Trattamenti Termici*, 1959, **2,** Jan.–Feb., 9–14, 29) [In Italian] Two problems are examined – first the relation between the structure of the steel at various points on the hardened surface and its variation during reheating and secondly the formation of cracks during quenching. A detailed description of experiments is given. The conclusions are (1) that three structures are present after the rapid reheating of the steel with 0·45%C causing formation of supersaturated ferrite, supersaturated martensite, and martensite, (2) that the tendency for cracks to develop results (*a*) when the maximum limit of 0·55%C in non alloy steels and from 0·4% in alloy steels is exceeded (*b*) from the same limit with 0·03%P, (*c*) from the same limit for 0·3%S with 0·01%P.

Trends in the further development of the technology of heat treatment of metals (*Metallov. Obra. Met.*, 1959, (5), 2–6) Uses of induction heating are reviewed and the extended use advocated. The hardening of automobile gears is described. Non-ferrous applications are included.

Speed missile parts output with induction heating L. C. Porter (*Iron Age*, 1959, **183,** Feb. 5, 86–87) A four-station induction heating plant is described for brazing, soldering, sintering, and tempering small parts accurately and quickly.—D.L.C.P.

Induction heating equipment is fast, flexible, economical (*Steel*, 1959, **144,** April 6, 146–149) The advantages of induction heating and factors governing choice of equipment are briefly dealt with. Typical applications are described.—A.G.

The role of hydrogen in the nitriding of steel A. A. Yurgenson (*Fiz. Met.*, 1959, **7,** (1), 110–115) During nitriding, the carbon on the surface of the steel reacts with the gaseous phase forming gaseous compounds (cyanides and probably carbon compounds). A decrease in carbon content of the surface layers lowers the surface hardness of the nitrided layer and increases coarseness.

Reducing the thickness of the decarburized layer in carbon and alloy steels C. Dohotaru (*Mat. Constr. Masini*, 1959, **11,** (2), 106–111) Three methods are suggested: covering the steel surface with copper, annealing in a methane atmosphere, annealing with cast iron chippings. The third method of annealing in boxes with cast iron chips gives the best results although it is the most laborious and time-consuming.

Heat treatment of ductile iron W. D. McMillan (*Mod. Castings*, 1959, **35,** April, 77–78) Three types of heat treatment for ductile iron castings are described namely; a full ferritizing annealing; a sub-critical annealing for machinability retaining 'as-cast' tensile properties; and a two-temperature normalizing for small castings.—A.G.

New process of heat treatment of forgings A. D. Assonov (*Metallov. Obra. Met.*, 1959, (5), 51) Forging is stopped above the Ac_3 point and the pieces are placed in a chamber for slow cooling. Its application to several steels and for various purposes is described.

Design and manufacture of a channel furnace for the annealing and tempering of tubes F. Guillemin and M. Barré (*Mét. Constr. Méc.*, 1959, **91,** May, 383–385, 387) The design, construction, control equipment and operation are described of a gas-fired heat treatment furnace constructed at the works of Lorraine–Escaut for plain carbon and special steel tubes; the dimensions of the tubes treated were up to 15 m long, external diam. 35–152 mm, wall thickness 3–16 mm.

Electric salt bath furnaces for wire annealing C. Albrecht (*Draht.*, 1959, **10,** May, 219–221) The advantages and economic limitations of this method of wire annealing are discussed, and features of design, and types of bath used are dealt with.

Effect of austenitising conditions on the transformation charactersitics of high-speed steels A. Rose, L. Rademacher, and J. M. van Wyk (*Stahl Eisen*, 1959, **79,** Sept. 3, 1243–1258) The term 'austenitising condition' is defined and its relationship to hardenability of high-speed steels explained. A photometric method for the determination of the carbide content is described and results are reported. Tempering behaviour is discussed as well as transformation characteristics including pre-eutectic carbide precipitation, pearlite field, bainite zone, and martensite transformation. The chemical composition of the five steels used are listed.—T.G.

Continuous furnace cyclic anneals forgings (*Metalw. Prod.*, 1959, **103,** May 29, 944–945) An account of the furnace installed by the Caterpillar Tractor Co. Ltd in Glasgow with a 42 in. conveyor and a loading height of 22 in. taking 2000 lb/hr of work on Ni–Cr trays and having six separate heating zones with a total consumption of 475 kW.

Pearlitic and malleable irons heat treated automatically L. E. Emery (*Foundry*, 1959, **87,** May, 82–87) A description is given of the layout and operation of an automatic annealing and heat treating plant with controlled atmosphere for the production of pearlitic malleable cast iron.

The foundry heat treatment department R. Gabbertas (*Edgar Allen News*, 1959, **38,** April, 80–82) Continuous operation is discussed and various furnace and quenching plant designs.

Isothermal quenching of carbon steels from high temperatures N. N. Lipchin and P. A. Sten'kin (*Metallov. Obra. Met.*, 1959, (5), 69–60) Heating conditions to conserve a fine-grain structure are given.

Heat treatment of steel springs O. Dorigo (*Trattamenti Termici*, 1958, **1,** Sept.–Oct., 6–9, 24–26) [In Italian] The writer distinguishes between springs made with steel which has undergone heat treatment at the semi-finished stage and springs which are subjected to heat treatment in their final form. In this

first article the production of springs by the first method is examined.

The tempering characteristics of low-carbon low-alloy steels K. J. Irvine and F. B. Pickering (*JISI*, 1960, **194,** Feb., 137–153) [This issue].

The effect of the rate of heating on the recrystallization texture of transformer steel K. V. Grigorov, K. A. Malyshev, L. V. Mironov, N. M. Rodigin, and B. G. Sazonov (*Fiz. Met.*, 1959, **7,** (2), 305–306) Experimental results have established that an increase in the rate of heating causes a continuous decrease in the rate of development of the structure corresponding to a given temperature. Keeping the specimen at a given temperature only results in an insignificant increase in the rate of development. A rate of heating of 1°/min produces a texture 95% complete, while a rate of 300–1000°/sec gives a texture 25–30% complete. The rate of heating does not influence the type of texture.

FORGING, STAMPING, DRAWING, AND PRESSING

Notes on the maintenance of large hammer and press forges A. Stark (*Rail, Steel Topics*, 1959, **5,** Spring, 34–39) Foundations, hammer blocks and tups, pistons and rods, and other equipment are reviewed.

Hot-forging stainless steel bolts (*Metalw. Prod.*, 1959, **103,** April 24, 733) A hot-forging plant recently installed at the works of Sandiacre Screw Co. Ltd, to produce stainless steel bolt blanks uses a Wild–Barfield H.F. induction furnace to provide fast, localized heating, prior to forging. The furnace can heat a ⅝ in. dia. billet to 1150°C in 8 sec.

The development of a practical forgeability test A. T. Viggiano and G. Sachs (*PB* 151153, Dec. 1956, pp 32) An expansion test using a press as power source is described. The procedure appears promising as a test of ductility.

Automatic work-handling equipment in the Vauxhall press shop (*Machinery*, 1959, **94,** May 20, 1153–1155) Units are described and illustrated.

New press for steel foundry (*Edgar Allen News*, 1959, **38,** April, 78–79) An account of the 250-t press installed in the straightening shop is given. It is intended to restore to shape any castings found to be out of register owing to contraction stresses.

Design principles for cold pressed steel components H. D. Feldmann (**Konstruktion*, 1959, (3), 82–89) The method and its advantages are set out with ten rules for guidance. Quantity required, type of steel, shape to preserve regular metal flow, tolerances, surface condition, drawings to be made, tool casts, avoidance of alterations, principles of design and minimizing of machinery are the points considered.

Rule-steel dies stamp tough material C. Hazzard (*Metalw. Prod.*, 1959, **103,** May 1, 774–776) A method of die construction using rule steel braced with plywood is described and the results are given.

Transformation of sheet metal in the automobile industry. II. Problems of stamping and press tooling J. Philippe (*Techn. Moderne*, 1959, **51,** Feb., 122–128) Conditions governing the stamping operation are treated theoretically and with examples. Practical data on methods of stamping are given, reference being made to press tooling.

Auto press perforates strip to any length (*Metallw. Prod.*, 1959, **103,** April 24, 725–726) An automatic method using a specially-adapted press and controls is used to perforate and blank off standard width strip to any of a wide range of lengths, using a standard Hordern, Mason and Edwards standard 25-t press adapted by the users, AC-Delco of Southampton.

Fabricating and finishing toolsteels for aircraft parts P. E. Ruff (*Met. Prog.*, 1959, **75,** April, 97–102) Techniques are described for the forming, welding, heat treatment, and finishing of H11 alloy steel, developed by North American Aviation.

Design limits control costs in forming steel tubing (*Iron Age*, 1959, **183,** April 16, 126–128) Recommended limits are given for the common methods of forming welded steel tubing, including swaging, flanging, and flaring, upsetting and spinning.—A.G.

Leaf-spring manufacture Richard Berry & Son (*Autom. Eng.*, 1959, **49,** April, 150–157) An illustrated account of the fully mechanized plant at West Bromwich. Si–Mn steel is used, sheared to length, punched, the longest leaf is heated at the ends to 950° and curled for attachment to the chassis. The method of reinforcement for racing cars is shown. Heat-treatment and quenching, shot peening, and assembly are then described.

Influence of the surface boundary layer on the frictional behaviour of austenitic materials in cold-forming in the deep-drawing process H. Wiegand and K. H. Kloos (*Metalloberfläche*, 1959, **13,** Aug., 229–233) The instability of austenitic substances to plastic deformation was utilized to study the occurrence of boundary lubrication conditions in deep drawing. The martensite constituents detected radiographically in the boundary layer were used to evaluate qualitatively the friction and wear properties of various high-pressure lubricants (11 refs).

Annealings and dies in process drawing of wire F. A. Mohrnheim (*Wire Wire Prod.*, 1958, **33,** Dec., 1465–1468, 1507–1508) A basic equation is developed for calculating percentage reduction in area and is used to illustrate the relationship between multiple annealing and drawing steps.—A.G.

A compound system for wire drawing machines A. T. Stoddart (*Wire Wire Prod.* 1959, **34,** April, 458–460, 496–497) A system described for the cooling and clarification o wet type wire drawing compounds.—A.G.

L–D Steels in wire manufacture A. Legat and E. Fogy (*Wire Ind.*, 1959, **26,** Jan., 52–53, 64) Because of the lower content of N, P, and S, L–D steel is said to be a superior material for wire drawing. Examples given are the production of netting, roofing nails, bolts, and rope wires.

Elimination of the carbide lattice in forgings from KhG and KhVG steels I. P. Zabaluev (*Stal'*,1959, (6), 567) A note from Dneprospetsstal. Forging at 1150° with a final temperature of 750–800° with slow cooling is used.

Forgeability of transformation-free alloy ingots. II. Relationship between high-temperature tension and bending susceptibility and as-cast structures of Timken 16–25–6 T. Yamane and G. Mima (*Tetsu to Hagane*, 1959, **45,** Jan., 21–26) The results of static and dynamic bending and tensile tests applied in various directions relative to the structure are reported. Best results are obtained when ingots are forged so as to avoid the direction parallel to the columnar axis as far as possible.—K.E.J.

The process taking place in punching steel and non-ferrous metals with round dies R. Dies (*Maschinewelt Elek.*, 1959, **14,** 3/4, 67–72) The influence on the punching process (in steel and non-ferrous sheet) of the material to be punched. Surface conditions and lubrication are discussed.

Now you can form ID profiles (*Steel*, 1959, **144,** Feb. 16, 150–151) The method of operation and applications of a new type of machine, 'Intraform' are described. The machine can form profiles in open or blind parts and tubes, form laminated tubing and effect other operations. It can handle ferrous or non-ferrous parts up to 5 in. dia. and 75 ft long using relatively inexpensive tooling. In a typical operation, the workpiece is formed between rotating dies and a fluted mandrel.—D.L.C.P.

New developments in hydraulic high-speed presses for open forging H. Hessler (*Werkstattstechn.*, 1959, **49,** April, 217–223) New developments in hydraulic forging presses are described, with reference to under-floor drives, and to newly-developed controls in association with the mechanization of high-speed forging operations.

Production of steel nuts by a scrapless cold pressing method F. Wiesner and O. Modraček (*Hutn. Listy*, 1958, **13,** (11), 1051–1056) Researches leading up to the design and application of automatic equipment for the cold-pressing of nuts in Czechoslovakia are described. The machines were developed mainly on the basis of blueprints of existing Soviet presses. The mode of operation is similar to that employed in the Waterbury-Farrel automatics.—P.F.

Metal-ceramic and steel dies for grooving steels A. B. Frenkel' (*Stal'*, 1959, (5), 468–471) The designs for dies for drawing sections which do not require machinery, thus eliminating chips and swarf are discussed, also the materials used and their heat treatment and finishing.

The introduction of cooled piercers in the disc piercing mill N. E. Protakii and P. D. Mavrodii (*Stal'*, 1959, (6), 546–550) A new form of piercing head is described which reduces wear. Their dimensions, wall thicknesses, method of production, and the grades of steel suitable for construction are given. Fully automatic operation of the mill was rendered possible by their use.

Preventing the occurrence of premature cavitation in the piercing of high-alloy steels O. A. Plyatskovskii and G. P. Pishchikov (**Stal'*, 1952, (4), 330–336) Trials are reported on the piercing mill variables necessary to avoid rupture in the centre of the workpiece producing cavities with torn surfaces which give rise to surface cracks and tears on further deformation. Ferritic and austenitic grades were used on a laboratory barrel piercing mill and inlet cone angle, temperature and degree of reduction were varied. The mechanism of cavity formation is discussed and various expressions are derived and criteria are suggested and recommendations are made for suitable parameters.

On the assessment of the capacity of sheet steel for deep drawing B. M. Ovsyannikov and L. T. Timoshuk (*Stal'*, 1959, (6), 560–562) A test simulating practical conditions is described. Two steels were used and the effect of hardness on drawing properties was confirmed.

The production of hollow bodies of steel by drawing (*Usine Nouv.*, 1959, **15,** April 2, 29–30) An account of the process, the steels to which it is applied and its uses.

The bright drawing of steel profiles H. Preussler (*Draht*, 1958, **9,** Nov., 435–440) An outline is given of the bright drawing process, preparation and heat-treatment, examples of sections, and economic factors.

Wear measurements during the drawing of steel rods by radioactive dies W. Lueg and P. Funke jun. (*Stahl Eisen*, 1959, **89,** July 9, 996–1002) Cemented carbide dies made of 90:10 WC–Co were rendered radioactive by neutron bombardment and the radioactivity of the surface of the steel rod drawn through the die was determined from a layer 2 mm thick that was machined off the rod. The wear experiments were made with rods of different surface quality and a number of lubricants. The results obtained are reported in graphs and diagrams; it was found that dry-drawing soap best protects the die from wear and that any surface treatment of the rod should be done immediately before working, as even short storage of the rods allows the formation of an almost invisible rust film which markedly increases wear.—T.G.

Introduction of a process for drawing low-ductility steel wire with heat applied N. P. Khetvin (*Stal'*, 1959, (6), 551) A research note from the Hammer & Sickle works. A special gas-heated furnace for drawing R18 and EI701 steels at 280–320° from 6 mm to 4·5 mm in 4 passes at 10–12 m/min, is described.

Developing conditions for making silver steel to a minus tolerance of 5 μ (551) Use of centreless grinding machines for producing the steel to a tolerance of —0·01 mm in the intermediate state and 5 μ at 6 m/min, removing 0·075–0·05 mm in the roughing and 0·025–0·05 mm in the finishing pass is described.

Rheinhausen wire mill – a modern continuous single-purpose mill W. Schulz (*Draht*, 1959, **10,** Feb., 41–49) An illustrated, detailed account is given of the wire drawing plant and ancillary equipment of Hüttenwerk Rheinhausen.

Trials on a hydraulic 25-t rod drawbench F. Wever, W. Lueg, and P. Funke jun. (*Forsch. Wirts. Nordrhein-Westfalen, No.*473, 1957, pp. 22) After outlining experiments carried out by the Max Planck Instituts für Eisenforschung, the limitations of the equipment are pointed out, and a description is given of an improved experimental installation designed to operate under conditions such as are

found in modern industrial plant. Details of the installation and of the measuring instruments are given, followed by an account of work carried out on the drawbench.

Yield-point lowering in a thin surface layer of metal in wire drawing as affected by the dose of surface-active substance added V. M. Korbut (*Doklady A.N.*, 1959, **124**, (1), 72–75) Experiments were carried out to measure the force used in wire drawing as related to the number of monolayers of stearic and oleic acids at different temperatures used as lubricants. It is concluded that even a small number of adsorbed layers, especially at 100°C, produces a marked effect and leads to a marked yield point lowering (plastification) of Cu and Al rods through a 8 mm opening.—S.I.T.

Principles of the design of draw benches and their auxiliary equipment F. Grah (*Stahl Eisen*, 1959, **79**, July 9, 990–996) An illustrated review of the design of drawing benches during the last 80 years.—T.G.

Ramming unsharpened rods into the draw plate R. Birman (*Stal'*, 1959, (4), 378) A ram is described and the clamping arrangements are shown. One pair of dies takes rods from 15 to 61 mm dia.

The die temperature of wire-drawing dies. I, II. T. Nishioka (*Nippon Kinzoku*, 1958, **22**, May, 225–229; 229–233) [In Japanese with German summaries.]—K.E.J.

Designing for steel extrusions J. J. Barrett (*Prec. Met. Mold.*, 1959, **17**, May, 68–69) Sections are shown and parts are illustrated. General notes on design are given.

ROLLING MILL PRACTICE

Topical problems for rolling mills (*Met. Constr. Masini*, 1959, **11**, (1), 48–53) [In Rumanian] A comparison is drawn between the Russian and Rumanian equipment and suggestions are offered for improvement.

Method of predicting spread during open rolling passes C. Somville (*ATB Métallurgie*, 1958, **1**, (5), 139–147) Marini's theory of spread during rolling is expressed by nomogram tracings (included in the text) which simplify the application of the theory. The limitations of their use are defined, and calculations are developed by which the nomograms can be used for other shapes of passes.

Influence of the shape of the oval and the diamond on the cross-sectional reduction obtained after each roll pass C. Somville (*ATB Métallurgie*, 1958, **1**, (6), 169–176) Based on the method developed by the author (see previous abstract) by which the coefficient of reduction can be determined for different sections, the influence of type of roll pass design on reduction is examined, with reference to the pure geometrical forms – oval, square, and diamond.

Investigating the possibilities of deformation of spheroidal cast irons by rolling I. Dragan and C. Rizescu (*Studii Cercetari Metalurgie*, 1959, (1), 73–82) It has been shown experimentally that it is possible to roll s.g. cast irons. On a factory scale it was rolled with reductions similar to those for normal steels. The temperature of the blanks was between 800 and 1000°C. Below 850°C rolling presents great difficulties, and cracks form with great reductions. Above 975°C there is a danger of overheating and cracks appear after a first pass. With a rapid rolling speed and with reductions exceeding 20% a number of passes can be made before the temperature falls appreciably.

Deformation of steel plate P. Blain (*Centre Doc. Sidér. Circ.*, 1958, (7), 1511–1513) Bending of rollers is briefly discussed. Static methods of measurement of deformation are shown to be unsuitable. A simple dynamic method is outlined, which has been successfully tested on a small cold-rolling mill.—A.M.A.M.

Effect of prestraining of rolling mill stands on the accuracy of the rolled products O. Pawelski (*Stahl Eisen*, 1959, **79**, Sept. 3, 1295–1297) The author reviews, and comments on, a publication by P. Ortner (*Klepzig-Fachber.*, 1958, **66**, (11), 421). Summarizing the mathematical treatment it is concluded that the rolling accuracy is not improved by prestraining the stands.—T.G.

The pressure of the metal on the work rolls and its measurement J. Jonca, Z. Kazior, and J. Rabaski (*Hutnik*, 1958, **25**, (11–12), 492–497) Constant measurement of roll pressure permits rolling to be conducted under optimum conditions, maximum plant utilization and rapid detection of disturbances in the rolling process. Moreover it provides the constructor with data for future mills and confirmation of scientific theories. In operation, measurements may only be made by electrical induction and tensiometric methods. Probes developed at the Ferrous Research Institute in Gliwice are described. Their use is especially recommended in cold rolling mills and hot reversing mills, the tensiometric type (range 30–1500 tonnes, accuracy (±1–2%) for the former, since their accuracy is greater than that of the induction type (±5%).—M.T.

Tests for the determination of the rolling force and power requirements in a Mannesmann tube-piercing mill A. Geleji, E. Kiss, and G. Dévenyi (*Stahl Eisen*, 1959, **79**, Sept. 17, 1352–1356) The pressures encountered in a Mannesmann tube-piercing mill were measured at seven points with strain-gauges, at the same time the power requirements of the motor were recorded oscillographically. Correlations of the two measurements give information on such effects as dimensions of the blanks, position, shape, and state of wear of the punch, rolling temperature, and the surface quality of blanks on rolling force and power requirements. The results are presented in graphs and tables.

Effect of deformation of the surface texture on rolling resistance J. Halling (*Brit. J. Appl. Phys.*, 1959, **10**, April, 172–176) Measurements of the variation in the coefficient of rolling resistance with increasing load for hard steel rollers on steel surfaces have been made. Initial value and rate of change are both reduced by a series of loading cycles in which the maximum load in any given cycle exceeds the maximum load in the one before. Increasing yield stress also raised the coeff. Interpretations are given on the hysteresis loss concept and the requirement for a smooth roller to surmount irregularities.

Introduction to rollmaking D. de W. Marais (*Eng. Found.*, 1959, **24**, April, 104–109) A review of the production of rolls for all purposes of cast and forged steel, cast iron or alloys. Constituents (C, Mn, S, P, Si, etc.) of cast iron and its melting and chilling are briefly considered and the microstructure is described.

Rolls for rolling mills. Part 2. R. A. Villanueva (*Ing. e Indust.*, 1959, **26**, Jan.–Feb., 83–87) The manufacture of the metal for chill cast iron rolls and the influence of its composition on the required properties are discussed.

Better heat profile control for sheet mill rolls P. F. Zasukha and V. A. Shilov (*Stal'*, 1959, (8), 721–723) To maintain camber, especially after wear, rollneck temp. conditions were examined by thermocouple placement and controlled to maintain true cylindrical profiles during rolling, especially of tinplate. It was found possible to improve the quality of strip.

Roll grinding machine (*Machine Shop Mag.*, 1959, **20**, May, 283–289) A description of three heavy-duty types with grinding capacities of 32, 42, and 66 in. dia.

Cast rolls get long service (*Iron Age*, 1959, **183**, Jan. 22, 72–73) The advantages of casting tool-steel forming rolls roughly to shape before machining are described. There is a 25% reduction in machining time, and their service life is excellent.—D.L.C.P.

Contoured grinding wheels tackle rod mill steels (*Steel*, 1959, **144**, April 13, 122) In the process described the multiple grooves in rod mill rolls are formed with a crush-dressed contoured grinding wheel. Improved life and shorter machining times are claimed.—A.G.

Increasing steel roll wear resistance by hard-facing L. F. Molotkov, A. L. Kryzhanovskii, E. M. Bortunov, G. N. Burkhan, G. P. Klimenko, and L. M. Kuznetsova (*Stal'*, 1959, (8), 716–720) The life of the rolls was greatly extended by hard-facing with 60 KhG steel or stainless welding rod.

The determination of the frictional losses on roll neck journals when water is used as a coolant and lubricant E. Wenger (*Stahl Eisen*, 1959, **79**, Sept. 3, 1263–1268) A method is described in which the frictional losses of open roll-neck journals are estimated with satisfactory accuracy from the thermal energy picked up by the cooling water. The sources of error which would impair the results are enumerated and it is shown that with sufficient care these can be eliminated. Owing to the permanently changing load on the journals no friction coefficient could be determined from the results of the experiments.—T.G.

The new BHP slabbing mill (*Austral Eng.*, 1958, Dec. 8, 55–57) Features of the £8,750,000 mill put into operation in 1958 are described.

Combination wide flange beam and structural mill built by United Engineering for Dorman Long Co. Ltd A. Wilson (*United Effort*, 1959, **39**, (2), 7–17) An illustrated account with plans, roll schedules, and a table of beam sections.

Rolling the first light-weight I-sections in Czechoslovakia E. Červený (*Hutnik*, 1959, **9**, (5), 150–153) I-beams, 6 in. high were rolled with a centre section 0·2 in. instead of 0·25 in. thick, the latter conforming to Soviet Standards. It was found that economies arising from the saving of steel would be lost due to a more complex technology of manufacture, except in very modern mills.—P.F.

Yield of heavy plate per ingot of rimming steel Dargent (*Centre Doc. Sidér. Circ.*, 1958, (9), 1919–1927) Factors affecting yield, including steel quality, density, and weight of ingots etc. are briefly discussed. The importance of greater control over width and thickness of the rolled ingot, as well as of ingot-weight, are stressed.—A.M.A.M.

Some aspects of plate-mill design and layout A. Marshall (*JISI*, 1960, **194**, Feb., 240–248) [This issue].

Hot rolling operation with a Steckel mill at Westfalenhütte in Western Germany K. Nisimura and A. Fuse (*Nihon Teppan*, 1959, **10**, March, 10–18) Full details of the plant and its mechanical auxiliaries, pass schedules and operating results are given.—K.E.J.

Electrical equipment of the Steckel mill at Westfalenhütte A.G. in Western Germany M. Yamagi and M. Sagawa (*Nihon Teppan*, 1959, **10**, March, 19–22) Details are given of the mill, coiler, drive, roll, and screw-down motors and other equipment.—K.E.J.

Developments in electrical equipment for reversing plate mills H. S. Brown and A. P. Baines (*JISI*, 1960, **194**, Feb., 225–240) [This issue].

The 850/700/500 continuous billet mill E. A. Zhukevich-Stosha and O. P. Solov'ev (*Stal'*, 1959, (4), 336–341) A mill with various improvements including high-speed flying shears is described. It has 12 strands driven independently.

Some experiences in rolling with negative tolerances in Soviet rolling mills M. Kepka (*Hutnik*, 1958, **8**, (10), 336–337) Economic aspects of the method are reviewed. It is recommended that, as rapidly as possible, apparatus for the measurement of the dimensions and number of ingots rolled with negative tolerances should be installed, and that the wages aspect of the introduction of this technology into Czechoslovakia should be considered.—P.F.

The modern continuous billet mill M. M. Shternov (*Stal'*, 1959, (5), 429–432) The advantages of mills with horizontal stands over those with alternate vertical and horizontal stands are set out.

High-strength inserts for the guides of rod mills I. S. Trishevskii, V. V. Klepanda, and A. V. Orlov (*Stal'*, 1959, (4), 342–344) Friction guides with steel inserts having boronized working surfaces are described.

The rolling of shaped sections with the use of automatic repeaters G. P. Klimenko (*Stal'*, 1959, (3), 248–252) The use of repeaters in the rolling of angles and channel sections is described. The layout of the mill and the systems of guides and looping circuits are considered in some detail.

Production of bent sections in roller-bending machines M. A. Leichenko (*Stal'*, 1955, (6), 526–534) In the shaping of strips on roller-bending machines the metal hardens, and this may be made use of under certain conditions. This technique makes it possible to produce very complex shapes and thus to reduce the costs of construction.

Special features of the rolling of heavy plates with a rolled edge in mills with vertical edgers M. E. Kugaenko, A. M. Meleshko, and M. V. Kovynev (*Stal'*, 1959, (6), 532–538) In rolling across the width in heavy plate mills, narrowing down of the ends takes place and rectangular plates with edges parallel along the whole length cannot then be rolled. It is in practice impossible to eliminate this narrowing altogether. The extent is related to the extent of lateral reduction. The fundamental conditions for the production of plates of uniform thickness is the widening of the ends of rolled stock before it is passed through the vertical rolls. Methods of producing this widening are suggested.

Effect of finishing-pass temperatures on the properties of thick sheet in the as-rolled and normalised states J. Choleva and M. Žídek (*Hutník*, 1959, **9,** (1), 7–13) In the case of killed and rimming steel sheet of 0·4–1·4 in. thickness with final pass temperatures in the range of 720–970°C, the authors' experiments show that annealing after rolling may be omitted. The steels, which had a tensile strength of up to 32 t/in² still complied with specifications.

Machines for separating pack-rolled sheets I. B. Rubinshtein (*Stal'*, 1959, (4), 344–347) Roller-type machines for packs of 2–8 sheets are described and a plan is given.

The asymmetrical triple roll plate roller – Type RMA (*Metalen*, 1959, **14,** May 30, 162–164) [In Dutch] This is a description of a machine made by the Swiss firm of Haesler for the cold bending of steel plate and strip. Tubes, T.U.I. angle iron, and flats may also be dealt with by mounting rolls of suitable profile. The machine is electrically driven in conjunction with oil-immersed reducing gears and universal joints on the rolls. Suitable devices against overloading the machine and overheating the motor are built in to ensure reliability during operation.—R.F.H.

Hot strip yield boosted by non-contact gauges (*Steel*, 1959, **144,** Feb. 2, 90–92) The value of an installation of width and thickness gauges on a hot strip mill is described. An improved width-gauge allows rapid adjustments to be made, and an X-ray thickness gauge automatically controls the roll screwdown.—D.L.C.P.

Finding the cause for cracked-edge formations on hot-rolled coils of transformer steels I. P. Zabaluev (*Stal'*, 1959, (6), 567) A note from Dneprospetsstal. Insufficient heating of the slabs after reconstruction of the mill was the cause.

A new cold rolling mill in South Africa P. Funke jun. (*Stahl Eisen*, 1959, **79,** July 9, 1013–1014) The layout and mode of operation of a new wide strip mill with subsequent cold rolling mill for the production of sheet and tinplate are briefly described.—T.G.

Improving synchronisation and increasing speed of production machinery H. Kirchbach and F. Zeunert (*VDIZ*, 1959, **101,** April, 385–392) Measures taken to improve synchronization and speed of crank-driven systems are illustrated in theory and practice by a detailed description of a modern cold-rolling mill

Cold roll forming practice in the United States W. G. Kirkland (*J. West Scot. ISI*, 1958–59, **66,** 51–92) A review of the process and plant, roll design, tolerances, and lubrication with an account of the production of typical sections.

Applications of cold-formed sections R. M. Kenedi and W. S. Smith (*J. West Scot. ISI*, 1958–59, **66,** 24–50) A description of the process and an account of the properties and behaviour of the finished sections, their uses and design principles, and fabrication on corrosion protection. Fields of application are outlined.

Increasing productivity of cold tube-rolling mills and the durability of rolling tools Yu. F. Shevakin, Ya. E. Osada, K. E. Gnezdilov, O. K. Semenov, F. S. Seidaliev, I. I. Zuev, N. K. Erokhov, G. N. Naumenko, S. T. Drobot, and N. G. Rumyantsev (*Stal'*, 1959, (3), 255–258) The use of a new method for designing roll passes has reduced total pressure and increased the durability of the rolling tools. Productivity was increased 15–20% and quality was improved by reducing the angle of taper of the mandrel.

New developments in the technology of high-alloy tube production O. A. Plyatskovskii, I. Yu. Korobochkin, and N. S. Kirvalidze (*Stal'*, 1959, (5), 436–441) The development of a process for tubes of 102–219 mm dia. is described. The theoretical basis is indicated and it suggested the use of high elongation factors during piercing. Extensions of the method are suggested.

Improvement of elongating machine work V. K. Yatsura (*Stal'*, 1959, (6), 552) A note from the Zakavakzsk Metal Works. The live rolls of the elongating machine on a type 400 tube rolling plant were changed from 6° to 7°30′ which increased elongation rate and temperature and reduced variations in dia. and wall thickness. **Use of non-detachable mandrels** (552) Water-cooled cast 12KhN3A steel mandrels are used in piercing machines of a 400 tube rolling mill. Their lives are tabulated.

Mechanisms for binding rod material into bundles (*Stal'*, 1959, (3), 261) A note on a machine for tying up rolled products in bundles of ~80 kg. It was developed for attachment to wire mill train.

Cold working. I. Shearing Y. Kasuga (*Tetsu to Hagane*, 1959, **45,** April, 451–462) A review, mainly theoretical, with 45 references.—K.E.J.

A thermoelectric method of inspecting rolled stock for shrinkage defects V. S. Isupov (*Stal'*, 1959, (6), 552) A note from the Serov Combine. The e.m.p. varies with C, Si, Mn, S, and other elements subject to segregation. Measurements at the axis and periphery of cross-sections of rolled stock give a measure of shrinkage.

The effect of straightening on the properties of type R-65 high-carbon heavy rails L. M. Shkol'nik (*Stal'*, 1959, (5), 451–456) Mechanical properties of straightened rails are determined, showing that the process increases elastic limit and u.t.s., has little effect on impact strength, and increases the fatigue strength of the head but slightly reduces that of the web.

Straightener takes kinks out of beam production (*Stal'*, 1959, **144,** Jan. 26, 80) A new type of beam straightener is described which has replaced four gag press straighteners with advantage. The new machine has 9 rollers in 2 rows, which straighten the beam horizontally, while lateral curvature is removed by adjusting the rollers sideways and by vertical rollers.—D.L.C.P.

Defects in low-carbon steel for flat-rolled products I. A. Sirel (*AIMME Proc. O.H. Comm.*, 1958, **41,** 143–156) The author describes and illustrates the major surface defects found in low-C steel slabs, namely scabs, sponge and burned steel, ingot cracks, thermal cracks, and pipe, and outlines the causes and methods of preventing their occurrence. Microscopical examination of slivers in tinplate is described, and their reduced occurrence when using low-Si Al as deoxidant is noted. Finally, brief attention is given to low-C Al-killed steel.—G.F.

MACHINERY FOR IRON AND STEEL PLANT

Detailed trials of sets of gas turbines operating on blast furnace gas A. Jaumotte and J. Baland (*Rev. Univ. Min.*, 1959, **15,** Jan., 3–18) The main characteristics of the two groups of turbines tested are given and the method of testing is described. Results obtained, after correction for the state of the air and gas, are compared with those after three months and six months operation to illustrate the effect of dust build-up.—A. G.

Standardization of steel mill crane control systems K. S. Kuka (*Iron Steel Eng.*, 1958, **35,** Dec., 61–68: discussion, 68–72) Proposals are made and discussed for the standardization of electrical control circuits for steel mill cranes.

500-ton hot metal ladle crane C. F. Simmers (*Iron Steel Eng.*, 1958, **35,** Dec., 124–131) The design and construction of a 500-t ladle crane are described in detail. The crane was of welded steel construction throughout.

Crane safety in the iron and steel industry (*British Iron and Steel Federation Sub-Committee Report*, pp. 54 + xvi).

Electricity in the steel industry: Introduction R. A. Lake (*Elect. J.*, 1959, **162,** Feb. 27, 559–560). Uses in the integrated works are reviewed. **II. Electric sheet and strip for magnetic circuits** E. Marks (Mar. 27, 927–929) Silicon steels are reviewed.

WELDING AND FLAME-CUTTING

Reactions between solid materials and their application to arc welding O. Knotek (*Metall*, 1959, **13,** Feb., 96–103) The types and compositions of coatings for covered welding electrodes are described, and the properties of new types of electrodes with sintered core rods are discussed.

Higher efficiency in submerged arc welding by the use of the open joint welding technique W. Schatz (*Schweissen Schneiden*, 1959, **11,** Jan., 23–29) The use of this technique is described for the welding of sheet up to 50 mm thick.

Repair-welding-first aid for foundry equipment L. D. Richardson (*Mod. Casting*, 1958, **34,** Dec., 26–28, 54–55) New techniques and the use of special welding filler alloys have extended the scope of repair welding in the foundry. Alloy steels, cast iron and Al parts can all be handled and some practical examples are given.—A. G.

The technology of production, processing and welding of the heat-resisting austenitic utility steel of the type MnCr(Ti) 17/7 F. Pobořil, F. Šícha, P. Jehlička, and J. Novotný (*Zvár. Sborník*, 1958, **7,** (4), 447–479) [In Czech] A report is given of detailed researches on the steel covered by the Czechoslovak Standard Specifications ČSN 17/481.—P. F.

Welding heat-resisting steels and alloys H. Gerbeaux (*Zvár. Sborník*, 1959, **7,** (3), 247–259) [In Czech] A survey is made of welding methods with particular reference to recent researches carried out at the French Welding Institute in Paris.—P. F.

Welding chrome-molybdenum steels resistant to heat and with high cold strength E. Pouillard (*Mét. Corros. Ind.*, 1959, **34,** Feb., 58–71) It is shown that the properties of Cr–Mo–V steels are satisfactory if welded with Cr–Mo–V coated electrodes under suitable conditions. The physical characteristics and microstructure of the welded material are discussed.

New welding methods for clad steels J. Čabelka (*Schweisstechn.*, 1959, **13,** Feb., 19–23) In this section the weldability of the stainless steels is discussed with reference to the improved weldability obtained in austenitic steels by the presence of ferrite, and the influence of oxygen on the properties of stainless steel.

The welding behaviour of chemically resistant Cr–Ni steels with higher Mo and Mo–Cu contents A. Schmidt (*Schweisstechn.*, 1958, **12,** Dec., 153–156) The steels concerned contained 17–18%Cr, 13–22%Ni, 2–5%Mo, and two steels contained 2%Cu and some Nb. Welding behaviour and some applications of the steels are described.

Fabrication of modern heat-resisting materials for the gas turbine industry H. Roberts (*Weld. Met. Fabr.*, 1958, **26,** Dec., 435–442) Steels and other metals, their heat-treatment and forming, welding and riveting processes and characteristics are reviewed.

Welded rings cut costs (*Steel*, 1958, **143,** Dec. 26, 68–69) The advantages of flash butt welding for the production of rings are listed. After suitable heat treatment, performance is said to equal that of solid parts.—A. G.

Portable equipment stress-relieves welds Electrothermal Engineering Ltd (*Metalw. Prod.*, 1959, **103,** Jan. 23, 150–152) Resistance heaters for application to welds are described.

Development of filler wire for welding army ordnance armour by the inert-gas-shielded consumable-electrode process S. N. Silverstein, R. P. Sopher, and P. J. Rieppel (*US Dept of Commerce Office of Techn. Services, PB* 131689, 1956, Mar. 31, pp. 27) Studies on the only suitable commercial electrode wire gave the mechanical properties required. Wires containing mischmetal were examined and a Mn–Ni–Mo–V ferritic steel and a Mn–Mo–V steel filler wire were developed which were further improved with 0·3% mischmetal. Cracking resistance was greatly improved as compared with the commercial wire.

Weldability of 12Cr (Cr, W, Mo, V) steel V. Pilous and F. Jandoš (*Zvár. Sborník*, 1958, **7**, (4), 463–479) [In Czech] Micrography and heat-treatment experiments were used in a study of the weldability of two such steels, one containing 1%, the other 4%W.—P. F.

The weldability of ferritic-pearlitic and ferritic steels used in welded rotors K. Pawera and V. Foldyna (*Zvár. Sborník*, 1958, **7**, (4), 480–499) [In Czech] Three low-alloy Cr–Mo–V steels and a Cr–Ni–Mo–V–W steel containing 12%Cr were studied. Correct welding technology was established for the former; on the basis of the data obtained it is hoped to specify the heat-treatment and welding technology for the 12%Cr steel in the near future.—P. F.

Properties of spot welds in low-carbon steels, particularly under fatigue conditions V. Gregor (*Zvár. Sborník*, 1958, **7**, (3), 260–311) [In Slovak] A detailed account is given of researches carried out on the subject over the last three years at the Welding Institute in Bratislava.—P. F.

Secondary hardening during welding of steels used at high temperatures and pressures V Foldyna and J. Wozniak (*Zvár. Sborník*, 1958, **7**, (3), 312–329) [In Czech] The process of molybdenum carbide precipitation, and the effect of the Mo/C ratio on secondary hardening of two low-carbon steels containing 0·47%Cr, and 0·51 or 0·91%Cr were studied by electron diffraction. The embrittlement was traced to the precipitation of the Mo_2C.—P. F.

Penetration control of fusion welding applied to sheet materials Bristol Aircraft Ltd (*Ministry of Supply, S & T Memo. No.*11/58, 1958, Sept., pp.22) Apparatus is described for continuous welding of thin sheet with control by infra-red radiation of extent of weld penetration.

Strength of welded joints in low-alloy steels at elevated temperatures W. B. Hoyt (*ASME Paper No.*58–PET–34, 1958, pp.15) A study with special reference to high-temperature failures in pressure equipment by cracking near welded seams. Tests on 1%Cr–0·5%Mo and 2·25%Cr–1%Mo steels are reported. Short-time tensile tests show no weakness in the weld. Creep-rupture tests show strength of the same order in weld and base metal. No inherent zone of weakness was found but visual appearance is some specimens suggested that further work is needed.

Co-operative research on the reliability of the controlled thermal severity test for studying the weldability of low alloy steels P. H. R. Lane and Commission IX of the Inst. Internat. de la Soudure (*Rev. Soud.*, 1958, **14**, (4), 201–212) This report deals with an investigation by the sub-committee B of the Institut into the reliability of the 'controlled thermal severity test' developed by BWRA for assessing the weldability of low alloy steels. Parallel tests carried out by different laboratories, the results of which are discussed in detail, indicate that the method can provide a basis for the assessment, but that it requires considerable experience and care to give reproducible results.

Weld flaw evaluation S. T. Carpenter and Roy F. Linsenmeyer (*Ship Structure Committee, SSC*–105, 1958, July 29, pp.117) A final report is presented on the studies of the ability of weld flaws to initiate brittle fracture. It deals with brittle fracture mechanics based on Griffith theory and Irwin's strain - energy release rate adaptations, with static tests on flawed butt welds, with static and dynamic tests on small butt weld flaws with and without residual stress and with static tests on weld flaws in a controlled field of high residual stress. The flaws were all simulated to represent various types of defect. Factors concerned in the initiation of brittle fracture were particularly examined and the environment was chosen accordingly. The great effect of residual stress is confirmed.

Welding in the metallurgical industry J. Čabelka (*Zváračský Sborník*, 1959, **8**, (1), 3–28) [In Slovak] The role of the welder in various sectors of the metallurgical industry is discussed and illustrated by examples. The development and significance of welding, in the construction of metallurgical plant as well as in metallurgy proper, likely to take place in the foreseeable future is assessed and considered.

Welding and metal forming in Russia A. B. Tesmen (*Met. Prog.*, 1959, **75**, Jan., 79–83) A résumé of a visit to Moscow in 1958 dealing with: friction welding, electroslag welding (the electric current passes between the electrode and the welded part through molten slag), forging practice (mentioning a new 77 000-t forging press), extrusion, and rolling of round periodic shapes.

Electro-slag method of welding metals of large thickness M. M. Barash, W. B. Heginbotham, and P. B. L. Oxley (*Weld. J.*, 1959, **38**, Feb., 132–134) Details are given of the electroslag welding process in which heat is generated by the passage of electricity through molten slag located between the edges of the parts to be welded and water-cooled copper plates. Typical applications are discussed.

Resistance-welded tube M. Perret (*Techn. Moderne*, 1959, **51**, Feb., 117–121) The author describes the electric resistance welding plant manufactured by Electrotube-Solesmes, and then outlines several electric tube welding processes.

Effect of backup variables on series spot welding of steel E. F. Nippes, W. F. Savage, and K. E. Dorschu (*Weld. J.*, 1959, **38**, Feb., 49s–56s) An investigation is reported on the effects of backup bar and stool combinations of varying electrical conductivity on the shunting currents and tensile-shear strength of series spot welds.—A. G.

Electro-slag welding in boiler construction O. Hajzler (*Zváranie*, 1959, **8**, (5), 136–140) Present practice is surveyed, and details of the technology used in the Vítkovice Steelworks in Czechoslovakia are given.—P. F.

Towards the standardisation of suspendable welding tongs for use in spotwelding large parts L. Plíva (*Zváranie*, 1959, **8**, (5), 142–148) [In Czech].—P. F.

New welding methods for clad steels J. Čabelka (*Schweisstechn.*, 1959, **13**, March, 31–35) Recommended technique for flame-cutting the edges of the material to be welded, the angles for the cladding and base material, selection of electrodes and welding technique are reviewed.

Tough ship plate W. J. Harris jun. and C. Williams (*Met. Prog.*, 1959, **75**, April, 66–71) Increasing knowledge of factors leading to brittle fracture and preventive measures makes it likely that no welded ships constructed since 1947 and conforming to A.B.S. Class A, B, and C will develop brittle fractures in normal service.

The development of welding materials H. G. Geerlings (*Metalen*, 1959, **14**, July 31, 210–213) Welding has undergone an extraordinary development in the last thirty years. The article considers also what was happening during the second half of the last and the early part of the present centuries. Particular reference is made to an article on the early development of welding written by Fox and Hipperson which appeared in the May 1951 issue of the *Sheet Metal Industries*.—F. R. H.

The technology of weld repair of spokes of railway engine wheels P. Hrbál (*Zváracský Sborník*, 1959, **8**, (1), 82–107) [In Slovak] The technology as developed at the Welding Research Institute in Bratislava is discussed, and the saving obtainable from such repairs, as well as testing methods are considered.—P. F.

Design and welding of alloy cast steel. Steam turbine applications L. W. Songer (*Mod. Castings*, 1959, **35**, May, 79–87) Aspects of the design, welding, and quality control of high-quality castings for steam turbine applications are discussed with examples. Economic factors are considered, and the advantages in making complex parts by welding together individual parts are pointed out.

Electric pre-heating for welding and stress relieving of pressure vessels (*Elect. J.*, 1959, **162**, April 3, 1009–1010) Work by the South of Scotland Electricity Board in conjunction with various firms and the devices evolved and estimates of cost are described.

Reconditioning of rolls, crane rails and forging dies by weld-surfacing K. Sniegon (*Zváracský Sborník*, 1959, **8**, (1), 64–81) [In Slovak] Methods for carrying out weld repairs developed at the Polish Welding Institute at Gliwitse are discussed.—P. F.

The precalculation of welding work, viewed practically F. Pečnik (*Schweisstechn.*, 1959, **13**, March, 25–31) Examples are given, with reference to tables and a nomogram, of the precalculation of operating times and material consumption in welding operations.

Control of steel weldability (*Met. Constr. Méc.*, 1959, **91**, May, 377, 379, 381) Precautions to be taken in the welding of some structural and special steels (Cr–Mo, austenitic and ferritic stainless, and heat-resisting alloys) are discussed (8 refs).

Straightening of weldments by local heating L. D. Veretnik (*Svarochnoe Proizvodstvo*, 1959, **32**, (5), 37–40) The principles and methods of such straightening are set out with examples from practice with large structures.—M. T.

Better training for welding engineers G. A. Nikolaev (*Svarochnoe Proizvodstvo*, 1959, **32**, (4), 1–3) A review of training facilities in the USSR, criticisms, and suggested improvements. In particular works experience should mean actual practical work on the bench and not merely work in the laboratory. Courses at universities should be specially prepared for welding students and not merely be a modification of general courses in metallurgy or engineering.—M. T.

Electricity in the steel industry. The contribution of the welding engineer D. Ewan (*Elect. J.*, 1959, **162**, May 29, 1547–1550) A review of coil joining processes, flash butt welding, multiple spot welding, strip line seam welding, and mash seam welding are described.

Cooperative investigation of a new welding electrode for stainless steel R. D. Wylie (*Weld. J.*, 1958, **37**, Sept., 4265–4325) The results of tests in several laboratories in evaluating a new welding procedure for use in high temperature steam piping are discussed.

New electrodes for welding type 1Kh13N-18V2B steel A. V. Russiyan and M. Kh. Shorshorov (*Svarochnoe Proizvodstvo*, 1959, **32**, (6), 9–13) It is shown that boron should be excluded, but 0·14–0·18%C and 1·4–1·8%Nb may be included in such electrodes. The beneficial effect of NbC on resistance to hot cracking depends on its modifying action (suppression of columnar crystallization, grain refinement, and reduction of grain growth at high temperatures). Electrodes so developed give good mech. props. on a par with the base metal.—M. T.

Metal powders for welding-electrode coatings F. Záhoranský (*Zváranie*, 1959, **8**, (5), 149–152) The production of high-melting-point ferro-alloys in powder form by the compressed air method is described, and the author's own experience in making high-carbon FeCr powders is discussed.—P. F.

Welding quality in naval construction C. Pombo (*Cien. Tecn. Solda*, 1959, **9**, March–April, 8, 84–8421, 1–14) Weld quality in the construction of welded hulls is examined with relation to design, procedure, types of electrodes, and quality control, and a number of radiographs of welds are reproduced.

Properties of welds made by the submerged arc method J. Lombardini and J. Zeke (*Zváracský Sborník*, 1959, **8**, (1), 50–63) [In Slovak] The technological and metallurgical requirements which need to be satisfied if high-quality welds are to be obtained are discussed.—P. F.

Deformation phenomena in welded structures J. M. Paris (*Cien. Tecn. Solda.*, 1959, **9**, March–April, 8, 85, 1–22) Longitudinal and angular deformation are considered, and the influence of joint length and transverse deformation of the weld are examined (16 diagrams).

Mechanical tests for the control of weldments S. Nadasan (*Met. Constr. Masini*, 1958, *Vienna welding congress supplement*, 28–33) [In French] A general review of the position abroad and specifications of the Rumanian bureau of standards for the various tests.

Study of effect of vibrations on solidification and structure of electro-slag weld metal F. F. Benua, I. V. Vologdin, and A. I. Katler (*Svarochnoe Proizvodstvo*, 1958, May, 1–5) The vibration of the metal in the weld pool improves structure by grain refining and increase in density. It is important that the vibration should continue throughout solidification. Investigations to avoid hot cracking and to avoid subsequent heat treatment are suggested.

Investigation of the kinetics of decomposition of austenite in steels during welding N. N. Prokhorov, E. L. Makarov, and V. I. Gospodarevskii (*Metallov. Obra. Met.*, 1959, (3), 13–16) Cold cracking occurs during austenite decomposition and the kinetics of transformation are largely determined by the resistance to cold cracking. Dilatometric studies of the temp. of complete austenite decomposition were related to crack-resistance. Magnetic measurements were also made with a new instrument and permissivity was also related to temp. Tendency to cold cracking can be evaluated from the kinetics established.

The properties of O.I.C. 15Cr25Ni5 Mo Austenitic weld metal at high temperatures V. A. Toropov (*Svarochnoe Proizvodstvo*, 1959, (1), 12–16) Sundry electrodes of this composition were tested; they produced a stable structure and satisfactory long-term operational properties (up to 100000 h) for temperatures up to 650°C. The deposited metal after stabilization at 800°C for 10 h had the following properties; yield point ≥22 kg/mm², u.t.s. ≥38 kg/mm², elongation ≥22% long-term strength at 650°C ~ 13 kg/mm², creep strength $\sigma_a^{650°}$ $\sigma_{(1\ 10)}^{650°}$—5 ~ 4 kg/mm² 100000 h, notch-impact strength after ageing at 650° for 3000 h ≥5 kg/cm².

The principal defects in gas welding E. Ehrenberg and H. Schmidt (*Schweissen Schneiden*, 1959, **11**, April, 121–126) By means of 42 macrophotographs, representative examples are shown, with comments, of defective welds, lack of root penetration, and of fusion in butt and lap welds.

The occurrence of cracks when welding stainless steel B. Mulder (*Lastechniek*, 1959, **22**, June, 113–115) [In Dutch] The author goes fully into the question of cracks that occur during the welding of stainless steel and goes on to discuss the causes of those that reveal themselves some time after the welding operation has been completed. These latter may be attributed to intercrystalline corrosion, unrelieved internal stresses, etc. He emphasizes that meticulous preparation of the material prior to the welding operation and the adoption of the most suitable form of weld can largely contribute to minimizing the trouble.

Hydrogen, 'Fish eyes' and tensile tests J. Izaguirre (*Cien. Tecn. Solda*, 1959, **9**, Feb., 2·1–2·8) A review is given of recent work on the effect of hydrogen in welding, and the relation between hydrogen content and tensile strength.

Influence of flame cutting on fatigue strength H.-D. Steffens (*Schweissen Schneiden*, 1959, **11**, March, 93–97) A discussion of the results of one French and two British papers on this subject. In all cases a substantial reduction in fatigue strength compared with the mechanically-worked material was observed.

MACHINING AND MACHINABILITY

Friction on relief face of cutting tool Ml Okoshi and T. Sata (*Sci. Papers Inst. Phys.. Chem. Research*, 1958, **52**, Dec., 216–223) Regardless of feed and relief angle the shear force on the relief face increases with contact length and compressive forces increase rapidly. The shear stress is practically unchanged by increase of contact length and is about equal to that on the rake face so that friction on both can be considered as due to metal shearing. Increase of flank wear is attributed to minute chipping owing to the high compressive stress.

Recent developments in the field of hard metals and hard materials for cutting purposes C. Agte and R. Kohlermann (*Technik*, 1959, **14**, April, 287–291) A review is given of developments in new types of hard metals for special purposes, for machining of high-speed steels and steel milling, materials on a heavy metal-boride basis, and cutting ceramics on an oxide-carbide basis (16 refs.).

Contribution to the demarcation of the effects of cooling and lubrication of a cutting oil on the machinability of steel H.-L. Hall (*Werkstattstechn.*, 1959, **49**, May, 247–254) Experiments are described with the object of delineating the cooling and lubricating effects of a cutting oil. It is shown that cooling can exert a negative as well as a positive action on the machining process, particularly in respect of tool wear and surface quality of the workpiece.

Ceramic tools take on big job J. W. Rodd and G. A. Hutson (*Iron Age*, 1959, **183**, Jan. 22, 61–63) The development and use of ceramic tools for rough turning alloy steels are described. In particular the machining of 120 mm tank gun forgings is dealt with. Advantages are increased tool life and stock removal rate, and avoidance of deflection of the workpiece due to thermal expansion. Important features of the method are: cushioning the cutting tip with thin Al foil; design and adjustment of the tool and chip breaker.—D.L.C.P.

Turning test on steel (*Metalen*, 1959, **14**, May 30, 161) [In Dutch] This is a short description of an instrument developed by the Koninklijke Demka Staalfabriken, N.V., Utrecht, for measuring over a wide range of cutting speeds at steady rates and cutting depths, the tangential forces (main cutting force) and the axial forces (feed force) when turning steels on the lathe. From the results obtained with the instruments an idea can be formed of the performance of the tool steels the company produces.—F.R.H.

Study of the hot workability of special shape steel. I. Influences of Cu, Sn and other factors on the hot workability E. Asano and A. Suseki (*Tetsu to Hagane*, 1959, **45**, Jan., 27–34) Special shapes, e.g. for sash bars for building or for parts of wheels, are considered. Materials with low workability (assessed by various tests) show seams and small cracks on the surface. Cu or Sn as impurities reduce the workability, and concentrate in the matrix just below the scale on heating; the concentrated phase is associated with surface defects.

CLEANING AND PICKLING

The cleaning of ingots J. Kostkuba (*Hutník*, 1958, **8**, (11), 368–373) Machining of the ingot surface is shown to be more economical if carried out while the ingot is hot. Lathes for the cleaning of rectangular tapered ingots are discussed.—P.F.

Holden (Osquench XII–10) salt bath process for descaling and desanding (*Ind. Heat.*, 1959, **26**, Jan., 161) The new chemical salt bath process dealt with is highly effective for removing scale and investment material in precision castings. Benefits include longer cutting-tool life, improved machining qualities, improved quality. With operating temperatures in the range 400 to 1100°F parts may be tempered or stress relieved at the same time.—D.L.C.P.

The development of the scale-breaking process for wire rod in Great Britain H. Krautmacher (*Stahl Eisen*, 1959, **79**, July 9, 1011–1012) Methods for obtaining a scale layer that is easily removable by two- or multiple-roll machines are briefly discussed, the type of lubricant used is described and the capital layout and running costs as well as the useful range of application and limitations are dealt with.—T.G.

The present position of mechanical descaling of wire H. Krautmacher (*Stahl Eisen*, 1959, **79**, July 9, 1006–1011) The author reviews the present position of mechanical descaling of wire from the technological and economical standpoints. The results of several studies are presented in graphs, tables, and diagrams. Advantages and disadvantages of mechanical descaling as compared with pickling are summarized and the limits of application of the mechanical process outlined.—T.G.

Removal of scale from rolled stock surfaces by reduction in sodium hydride V. F. Isupov (*Stal'*, 1959, (6), 552) A note from the Serov Combine. An electrically heated bath 6000 × 1800 × 1200 mm of 15–17 t NaOH at 370–400°C is used with not less than 2% NaH generated *in situ*. The surface is shielded with N_2 and a special float.

Flame scarfing bloom at rolling temperature N. V. Keis (*Stal'*, 1959, (6), 551) A research note from Chelyabinsk. Scarfing temperature is raised from 150–300° to 300–400°C with advantage.

Some remarks on pickling thin steel sheet B. Otta and J. Teindl (*Hutník*, 1959, **9**, (1), 17–21) Researches on the utilization of ferrous sulphate as pickling inhibitor in H_2SO_4 are reported. The inhibitor was found satisfactory particularly as regards the amount of H_2 entering the steel during pickling. Study the use of phosphoric acid for pickling is recommended, as its use would simultaneously solve the problem of the best inhibitor to use, i.e. none would be required.—P.F.

Pickling plants for wires and strip F. Rüb (*Draht*, 1959, **10**, Feb., 53–59) The mechanical equipment, preparation, and heating of the bath, removal of fumes, and material problems in the erection and operation of wire and strip pickling plants are discussed with examples.

A new method of pickling high-alloy steel tubes N. A. Bogoyavlenskaya and Ya. N. Lipkin (*Stal'*, 1959, (4), 347–351) An accelerated acid pickling method giving a light grey bright surface is recommended which avoids pitting, corrosion-cracking, and gives minimal loss of metal. Four grades of stainless steel were examined and 25 experimental quenching baths are tabulated. A bath with 1·5–2% HF and 8·0–8·5% HNO_3 was chosen.

The development of a continuous non-contact electrolytic method for pickling wire rod N. P. Khetvin (*Stal'*, 1959, (5), 640–641) A note on research at the Hammer & Sickle works. A two-bath laboratory method with cathode pickling in the first and anodic in the second is described, the effects of conditions on C-steel and stainless wires being observed.

The development of a method for pickling molybdenum sheets (461) A NaOH–$NaNO_3$ fused salt mixture is used.

Electrochemical degreasing of cold-rolled sheet V. P. Kochergin, M. E. Prostakov, and A. A. Trakasova (*Stal'*, 1959, (3), 252–254) Trials on the rapid (1–3 sec) electrolytic degreasing of sheet in an alkali solution are described. The process should be carried out at a c.d. of 10–15 A/dm² (25 A/dm² for emulsified palm oil) at not less than 80°C.

Should iron and steel be polished before electroplating? (*Metalloberfläche*, 1959, **13**, Jan., 25–26) The advantages of polishing before plating, particularly the undercoat of Cu before Ni plating, are discussed.

Experimental investigation of the smoothing process in electrolytic polishing S. I. Krichmar and V. P. Galushko (*Zhur. Fiz. Khim.*, 1957, **31**, (8), 1762–1766) Experiments on Cu are described.

Investigation of the processes taking place in the electrolytic polishing of aluminium and iron E. Lichtenberger-Bajza (*Metalloberfläche*, 1959, **13**, March, 65–71) In order to study the possibility of formulating a comprehensive theory to establish the mechanism of electrolytic polishing, the anodic process in the electrolytic polishing of Fe and Al was investigated. Tests were carried out on plain C and tool steels, and an 18/8 stainless steel. Anode potential variations and the passive surface layer were investigated.

Polarization mechanism of inhibiting structure etching in the electrochemical polishing of metals S. I. Krichmar (*Doklady AN*, 1959, **124**, (3), 621–624) A detailed mathematical calculation is applied to the process of electrochemical polishing of metals. It is concluded that under such conditions polishing can be achieved only on suppression of the structural etching. The aim of the mathematical calculation is to express the velocity of etching as a function of the current density and other factors.—S.I.T.

Electromechanical burnishing of metals B. M. Askinazi (*Metallov. Obra. Met.*, 1958, (9), 49–53) A heavy low-voltage current is passed through the part-tool contact and besides the smoothing action, hardness is increased. Tests on quenched steel are described and structures are shown. Wear resistance was greatly increased.

Multichamber unit for shock blasting of metal after descaling I. M. Sidorenko (*Stal'*, 1959, (4), 368) A unit of 5 chambers for washing, neutralizing, secondary washing, passivation and drying with live feed rollers, take-in, delivery, and discharge roller table is described.

Regeneration of used hydrochloric acid solutions (*Mét. Constr. Méc.*, 1959, **91**, March, 191–192) A description, illustrated by a schematic, diagram, is given of the operation of a plant,

installed in two parts, in which HCl is regenerated in a pickling installation by thermal dissociation of the separated $FeCl_2$. The process is at present suitable only for plant handling at least 1 000 t/month of steel.

PROTECTIVE COATINGS

A measuring instrument for the rapid determination of the thickness of metal coatings V. Breitling (*Metalloberfläche*, 1959, **13,** May, 145–147) An apparatus is described for the electrochemical determination of thicknesses of metal coatings on sheet and strip. The instrument can be constructed from standard equipment, and is also suitable for assessing the influence of fluids on metal surfaces and for measuring electrochemical potentials.

Installations for the hard chromium plating of tool and machine parts (III) E. Zmihorski (*Metalloberfläche*, 1959, **13,** April, 118–119) Designs of anode, cathode, and of the ventilation system are outlined in this part.

Automation in the electroplating of car bumpers L. Walter (*Metalloberfläche*, 1959, **13,** April, 103–104) A brief account is given of the new plant for plating bumpers in the automobile works at Lansing, Michigan.

Influence of heavy metal salts on polish and rate of deposition in the electroless deposition of nickel, together with a contribution to the reaction mechanism of electroless nickel deposition W. Machu and S. El-Gendi (*Metalloberfläche*, 1959, **13,** April, 97–103) The influence of pH value and the effect of additions of cobalt acetate, zinc sulphate, cadmium sulphate, and uranium acetate on the thickness and polish of the Ni deposit on Al sheet are investigated. A theory of the reaction mechanism in electroless Ni deposition is suggested.

Investigation of the mechanism of the inclusion of phosphorus in nickel coatings by means of the radioisotope ^{32}P K. M. Gorbunova and A. A. Nikiforova (*Zhur. Fiz. Khim.*, 1957, **31,** (8), 1687–1692) The mechanism of the inclusions of P in Ni deposits formed by reduction from solutions of Ni salts by hypophosphite was investigated by measuring the activity of ^{32}P tracers present as hypophosphite or phosphite. It was concluded that P is formed in the Ni deposit directly from the phosphite produced by the oxidation of hypophosphite.

Possibilities of chemical nickel plating J. L. Fiedler and J. J. Vanroyen (*Rev. Nickel*, 1958, **24,** (3), 53–63; *Draht*, 1959, **10,** April, 161–163) Various methods of chemical Ni plating are described, properties, advantages and disadvantages of the process are discussed, and examples of its application described and illustrated.

Remarks on the theory and application of fluxes in metallising in melts J. Teindl (*Sborník Ostrava*,) 1958, **4,** (6), 531–545) The theory of the application and use of fluxes, particularly in galvanizing, is reviewed, and the importance of the presence of Al in the zinc bath is discussed. On the basis of the author's experiments on dry and wet galvanizing, the latter method is shown to be more economical in practice. The recent theoretical and experimental work of A. I. Vitkin (*Izvestia AN*, SSSR, *Otdel-Tekh.*, 1956, **10,** (5), 154–156, and *Doklady AN SSSR*, 1957, **115,** (4), 710–713), in which the use of anhydrous $ZnCl_2$ is recommended, is discussed.—P.F.

The new galvanizing line at Greenings G. R. Armstrong, R. Bliss, and G. V. Globe (*Wire Wire Prod.*, 1958, **33,** Nov., 1376–1382, 1405–1406) The development work proceeding the construction of a new galvanizing line is described with details of the plant.—A.G.

Hot-dip galvanizing of grey cast iron P. Debouté (*Werks. Korr.*, 1959, **10,** March, 148–151) The importance of surface preparation in the successful hot-dip galvanizing of grey cast iron is emphasized, and illustrated by means of examples.

Combination of annealing and hot coating with the aid of salt baths A. I. Vitkin (*Doklady AN*, 1959, **124,** (5), 1105–1108) In order to find optimum conditions of annealing in salt baths, experiments were carried out on samples of steel strip immersed in salt melts and subjected to annealing and cooling under variable temperature and time conditions. It is shown that Zn and Sn coatings were successfully applied under these conditions.—S.I.T.

A use of galvanized steel. The production of special profiles for metal fittings (*Acier-Stahl-Steel*, 1959, **24,** April, 183–187) The sections are shown with a diagram of the continuous galvanizing train and illustrations of parts of the shaping rolls.

Effect of intermediate and final annealing of steel wires on the adhesion of thick zinc coatings D. Horstmann (*Stahl Eisen*, 1959, **79,** July 9, 1002–1005) The adhesion of thick zinc coats obtained by galvanizing processes on rimming steel wires is reduced by annealing the wire before galvanizing. Final annealing of the wire in bell-type furnaces did not affect adhesion as compared with hard-drawn wires. High P and N contents of the wire improve adhesion. It is concluded that annealing alters the surface properties of the wire.—T.G.

Hot-dip tinning of cast iron E. S. Hedges (*Giesserei*, 1959, **46,** April 23, 233–236) The advantages of the 'direct chloride' process are pointed out, the process is described, and the properties of the coating discussed.

Improvement of the finish of cold-tinned parts (*Usine Nouv.*, 1959, **15,** April 9, 38, from *Etain et ses usages*, 1958, (44)) Removal of excess Sn by centrifuging above its m.p. and the thickness of tin remaining is considered.

Aluminium coating of steel wire H. J. Godfrey (*Wire Wire Prod.*, 1958, **33,** Nov., 1349–1351, 1410) After a brief description of possible methods of coating steel with Al the hot-dip process is discussed and the importance of surface preparation is stressed.—A.G.

Mechanized hot-dip galvanizing (*Iron Age*, 1959, **183,** April 9, 106–108) The machine described controls the whole galvanizing cycle electrically and can handle both large and small parts. High outputs with a low manpower requirement are claimed.—A.G.

Flexible line automates hot dip galvanizing (*Steel*, 1959, **144,** April 27, 104–105) The hot dip galvanizing of small and large parts has been automated with electric controls and program timers. After pickling and galvanizing, small parts are spun in a centrifuge while large ones are quenched in a tank.—A.G.

Hot-dip galvanizing of sheet and strip J. Hawkins and E. J. Williams (*J. Australian Inst. Met.*, 1959, **4,** May, 49–60) The authors trace the development of the hot-dip galvanizing process, describing the equipment used and discussing the properties of the final product. The development of the bare materials is shown to have had a profound effect on the galvanizing techniques used and on the properties of the final product.—G.F.

Continuous galvanizing line put into operation of Osaka Works K. Waki (*Nihon Teppan*, 1959, **10,** March, 23–28) The line is of the Cook-Norteman type, producing tight coatings. Details are given of the installation.—K.E.J.

The role of lead in the hot galvanizing process N. S. Smirnov, G. F. Konovalov, I. A. Kakovskii, and I. B. Serebryakova (*Stal'*, 1959, (8), 764–767) Lead has been shown to improve wettability of iron by zinc where the bath contains dissolved Fe and this may be the mechanism of its effect in the process. With only 0·002%Fe in the bath, the effect of Pb is negligible. In using electrolytic Zn, a Pb–Zn alloy can be added as Pb–Sn is expensive.

The influence of hot-dip galvanizing on the notch toughness of structural steel WR St 37-2 according to DIN 17100 for various notch sharpnesses H. Wiegand and F. Nieth (*Metalloberfläche*, 1959, **13,** Aug., 254–259) The influence of hot-dip galvanizing on specimens in the as-supplied condition and after various preliminary treatments – heating to the zinc bath temperature, hot-dip galvanizing and after stripping the zinc coating, was examined by notch-toughness tests, using DVM and DVMF specimens (13 refs).

Atmospheric corrosion resistance and metal coatings J. H. Nicholls (*Product Fin.*, 1959, **12,** May, 65–67) Tinning of Cd-plated steel for use in printing is described, the so-called AHFO treatment. The surface is suitable for soldering and spot welding.

Brass-surfacing of ferrous metals by the flame-fluxing technique G. A. Asinovskaya, E. V. Belova, and H. M. Zelikovskaya (*Eng. Digest*, 1959, **20,** April, 155–156; from *Svarochnoe Proizvodstvo*, 1959, (2), 28–31) This article describes a flame fluxing technique developed in Russia by means of which a good quality of deposited metal is obtained without boiling out the Zn from the filler metal. The method is in full-scale production, and automatic equipment is being developed.

Galvanic deposition of cadmium F. I. Constantin and S. Zamfira (*Met. Constr. Masini*, 1959, **11,** (4), 281–286) Addition of carpenter's glue to the baths of CdI_2 increases cathodic polarization, as is also the case in the baths of $CdSO_4$. Any glue additions beyond 10 g/l have no further effect. Current efficiency in iodide baths is 99–100% while in sulphate baths it is 96–98%. The Cd deposit from electrolytes containing glue has a better adherence to the metal. Details of electrolytes and conditions of operation are given.

Progress on alloy plating. I. Tungsten and molybdenum alloys W. Safranek and L. E. Vaaler (*Plating*, 1959, **46,** Feb., 133–143) Compositions of baths, their properties and the properties of electrodeposited binary alloys of Fe, Co, and Ni with W and Mo respectively are reviewed. The mechanism of co-deposition is discussed (60 refs).—A.D.H.

Application and problems of metal spraying. A review of the process in the Union of South Africa J. F. Attwell (*Electropl. Met. Fin.*, 1959, **12,** April, 138–140; May, 176–178) Atmospheric corrosion conditions in South Africa and the absence of industrial fumes are reviewed. The use of sprayed Zn coatings on trucks and on steel windows in coastal areas and also the uses of sprayed Al for protection or decoration and of bronze are briefly considered. A brief review of equipment is given with a note on the repair of worn parts by metal spraying.

High frequency metallizing A. P. Vlasov (*Met. Ind.*, 1959, **94,** May 15, 391–393) An account of a Russian spray gun and its capabilities using steel wire.

Selective oxidation of metallic surfaces and the possibilities of its use against wear F. Barbas (*Usine Nouv.*, 1959, **15,** July 16, 41–42) Forms and properties of oxide layers on ferrous metals are reviewed with notes on other metals.

A method of passivation of ferrous alloys G. P. Mologskaya (*Svarachnoe Proizvodstvo*, 1959, **32,** (4), 42) Passivation of ferrous alloys liable to action of waterglass in an electrode coating may be affected in a solution prepared by dissolving 2 kg K_2CrO_4 in 20 l H_2, heating to boiling point, adding to it 75 kg Fe–Si and boiling for 15 min. This may be used on repeated occasions.—M.T.

The passivation of iron and steel in chromate solutions A. H. Kingsbury (*J. Australian Inst. Met.*, 1959, **4,** May, 12–18) The author reviews the different theories which have been put forward to explain the passivation of iron and steel in chromate solutions. It appears that both chromate ion adsorption and oxide film formation take part in the process.—G.F.

Atram phosphating processes in German cycle and car production (*Electropl. Met. Fin.*, 1959, **12,** April, 141, 133) A brief illustrated account of operations at the NSU Werke, Neckarsulm is given.

Automated phosphating line pays off in first year (*Steel*, 1959, **144,** Feb. 2, 82–85) The Timken roller bearing automatic plant is described, and illustrated. Five dip tanks are used in succession with radio-frequency control.

Anti-corrosive finish to Ferrous metals (*Ind. Fin.*, 1959, **11,** April, 53, 56) The Bostik 'Endurion' process, applied over phosphating, of anti-corrosive finishing is discussed, and its characteristics are outlined. Parts treated by this process remain serviceable for at least 16 times as long as when treated with dry phosphate, and four times as long as when treated with phosphate and oil.—G.F.

Handling cast-iron pipes through finishing processes (*Materials Handling News*, 1959, May 26; *Mech. Handling*, 1959, **46,** May, 295–296) Stavely Iron & Chemical Co. pipe handling and dipping in Angus Smith solution is carried out on two conveyor systems which are illustrated.

Plastic coated steel sheet (*Corros. Prev.*, 1959, **6,** April, 61–62) A note on the general proper-

ties and uses of Stelvetite polyvinyl chloride coated sheet, zinc plated on the back.

Oil refinery applications of thick-film synthetic coatings R. W. Maier, W. B. Cook, and R. B. MacQueen (*Corrosion*, 1959, **15,** April, 171t–178t) Details are given of the successful use on refinery equipment of hot-spray vinyl, catalyst-cured epoxy, catalyst-cured phenolic and catalyst-cured epoxy-modified phenolic coatings. These have reduced out-of-service time of equipment and have given longer coating lives in environments including water, oil, alkali, sulphuric acid, and polluted atmospheres. High-film-build alkyd coatings have also been used but service data are only available for the other coatings mentioned.—J.F.S.

Temporary rust protection coating K. A. van Oeteren (*Metalloberflache*, 1959, **13,** June, 181) Removable rust preventers for protection during storage and transport are enumerated and classified.

Evaluation of steam resistant coatings for carbon steel hospital ware E. G. Bobalek, W. R. R. Park, E. G. Bell, and W. R. Dawson (*Corrosion*, 1959, **15,** April, 202t–206t) The feasibility of replacing stainless steel with coated carbon steel for hospital ware subject to sterilization in steam has been examined. A wide survey of possible materials showed that alkyd, silicone, and vinyl coatings were unsuitable. So were rubber base, bituminous, urethane, and teflon formulations. A number of promising materials were discovered which have withstood 6000 h at 20 psi steam intermittently in sterilizer tests. These have included a few modified phenolics, modified epoxys, polybutadiene, and a polymonochlorotrifluoroethylene, which was best, but most expensive. Film thickness, surface preparation, and stoving temperatures must all be considered and imperfect coating application often caused failure.—J.F.S.

Strippable coatings: Keep products bright, clean, safe R. J. Fabian (*Mat, Design Eng.*, 1959, **49,** May, 110–115) A review of the application, properties, and uses of cellulose and vinyl coatings.

Testing of organic coatings for oil and gas well tubing C. Garner (*Corrosion*, 1959, **15,** May, *Technical Topics*, 121–124) Laboratory autoclave tests to simulate and accelerate service conditions for coatings for use inside oil and gas well tubing are described. Flat specimens coated with a wide range of organic coatings did not always give results comparable with those obtained on tubular specimens, which are preferred.—J.F.S.

On the β-ray tin coating thickness gauge for tin plate K. Takemoto and T. Fujii (*Toyo Kohan*, 1954, **3,** May, 28–32) Two gauges are described; ^{14}C is used and back scattering β-rays from tin and the base metal are measured. The gauge in which measurements are made by a redesigned Rauritzen electroscope has an accuracy of $\pm 6\%$, while that having an electrometer has an accuracy of $\pm 2\%$.

Mechanical testing of tinplate I. Kuno (*Toyo Kohan*, 1953, June, 65–70) A review, with 49 refs.—K.E.J.

Finishing tinplate in the flat J. T. Leonard (*Prod. Fin.*, 1959, **12,** Mar., 54–61, 76) Lacquering, printing, varnishing, stoving, etc. are described.

Molybdenum coatings H. W. Schultze, R. R. Freeman, and J. Z. Briggs (*Mat. Design Eng.*, 1959, **49,** Jan., 76–81) The properties of Mo coatings including adhesion, hardness, ductility, wear- and corrosion-resistance, etc. are discussed and uses are enumerated. The various processes for producing Mo coatings are briefly described and their merits stressed. Metal spraying, electrophoretic deposition, and vapour deposition are those most widely used.

Study of aluminium-coated steel. X. The behaviour of the outer aluminium layer on heating and its influence on the resistance to oxidation T. Saga and O. Miyakawa (*Nippon Kinzoku*, 1958, **22,** Apr., 177–180) To avoid flaking on heating, the Al layer should not be thicker than 20 μ. In the range of temp. between 500°C and the m.p. of Al, a heating rate above 15°C/min produces a smooth alloy layer by diffusion. Lower rates cause aggregation of the layer. With slow heating, a layer thicker than 30 μ shows poor oxidation resistance, and flaking instead of diffusion occurs at a rate of 4°C/min.—K.E.J.

Aluminium coating of steel B. O. Holland (*BHP Techn. Bull.*, 1959, **3,** Mar., 29–32) Electrodeposition is described. An $AlCl_3$–NaCl–LiCl bath is used. Work on the laboratory scale is relatively easy but technological application has not yet been achieved.

Metal spraying and welded structures W. E. Ballard (*Engineer Foundryman*, 1959, **24,** Jan., 43–50) The advantages from the aspect of corrosion resistance of welded structures protected by a sprayed metal coating are discussed with practical examples. Other applications of metal spraying such as reclaiming machine parts are briefly dealt with.—A.G.

Metal spraying in northern latitudes S. B. Giertsen (*Electropl. Met. Fin.*, 1959, **12,** Mar., 99–101) Complications in the cold climate of Norway and some comparison with hot dip galvanizing conditions are considered. Some uses are briefly noted.

Developments in metal pre-treatment R. E. Shaw (*Trans. Inst. Met. Fin.*, 1959, **36,** Spring, 107–112) Phosphate coating, alkaline derusting and various non-ferrous metal developments are reviewed.

Chromate conversion treatments. II. D. J. Fishlock (*Prod. Fin.*, 1959, **12,** Feb., 87–93, 116) Processes, mainly single-dip, are briefly described, mainly non-ferrous. A process for stainless steel is mentioned.

An ebonized finish for stainless tools (*Metalw. Prod.*, 1959, **103,** Mar. 29, 945) A note on a process using molten dichromate to give a black gloss finish.

Plastic-coated steel sheet F. H. Smith (*Sheet Met. Ind.*, 1959, **36,** Feb., 91–100, 118) A general review is given of production, joining, decorating and using and its properties are summarized. Uses are illustrated.

Vinyl-coated steel sheets: colour, pattern, protection (*Iron Age*, 1959, **183,** Mar. 12, 128–130) In a process developed by US Steel liquid vinyl resin is roller-coated on to carbon steel sheet giving excellent adhesion even after severe deformation. Properties and applications of this coated steel are discussed—A.G.

US Steel announces production of vinyl-coated sheet (*Iron Steel Eng.*, 1959, **36,** Mar., 140, 143) Method of production and properties of the vinyl strip-coating plant of United States Steel Corporation are described.

Warmth of colour and feel added to strength of steel (*Steel*, 1959, **144,** Mar. 9, 73–76) The production, properties and applications of US Steel's vinyl-coated sheets are described. Advantages of this material include choice of colour and texture, mechanical and chemical resistance, and low cost.—A.G.

Stove enamelling firm installs gas-fired conveyor ovens (*Ind. Gas*, 1959, **22,** Feb., 16–17) A brief account of the camel-back conveyor oven installation of H. J. Law and Co. Ltd, Wolverhampton, applying plastic coatings.

Thermal fracture resistance of ceramic coatings applied to metal. I. Elastic deformation J. H. Lauchner and D. G. Bennett (*J. Am. Ceram. Soc.*, 1959, **42,** Mar., 146–150) The authors have studied the resistance to thermal fracture of four ceramic coatings of the cobalt-bearing groundcoat type applied to enamelling-grade iron specimens. Coated-metal systems were considered in the unsteady state, symmetrically cooled, and in the absence of viscous or plastic flow. The experimentally-obtained thermal fracture data are correlated with the physical properties of the coated-metal systems and with stress development.—G.F.

Processing and painting of sheet-metal components W. Stein and E. Podmore (*Met. Fin. J.*, 1959, **5,** Mar., 101–110, discussion 110–112) Degreasing, phosphating, painting and coating of steel and non-ferrous sheet metals are reviewed.

Protective painting of coke oven plant R. Nichols (*Gas World*, 1959, **149,** Mar. 7, 48–50, 52) Failure of paints on two gas-holders and exposure tests made with preliminary results are described.

Surface protection with only primer and one top coat (*Ind. Fin.*, 1959, **11,** Mar., 42–43) Trials in Sweden are briefly described. The use of a thixotropic primer with red lead, calcium plumbate or zinc chromate was successful combined with a thixotropic alkyd finishing coat.

CLAD SHEET AND HARD-FACING

The effect of surface preparation on the adhesion of bearing metal to steel C. J. Thwaites (*Metallurgia*, 1959, **59,** Mar., 121–124) To investigate the effects of various pretreatments of steel bearing shells before hot-tinning and casting bearing metal on to them, several methods were examined and compared. Although shot-blasting can give an adequate bond between metal and bearing metal, pickling is to be preferred for the best results.

Comparative properties of hard surfacing alloys (*Mat. Design Eng.*, 1958, **48,** Dec., 121) A table of the alloys used in hard facing with their properties such as corrosion resistance, wear resistance and performance coefficients is presented.—T.G.

Babbitting of cast iron (*Eng. Foundryman*, 1959, **24,** Mar., 46–47) An account of the tinning and casting process and the structure and products obtained by the Kolene process.

Co-extruded parts can simplify design N. R. Gardner (*Mat. Design Eng.*, 1958, **48,** Dec., 91–93) Co-extrusion was developed to meet special service conditions necessitating the use of clad metals. A co-extrusion is produced by forcing two or more materials through a die at an elevated temperature. For instance, stainless steel for corrosion-resistance is combined with an inexpensive face of mild steel in a tube. The advantages and the limitations of co-extrusions are shown in a list.-T.G.

Ceramic-stainless bond beats high heat attack; seals pressure pick-ups (*Western Metalw.*, 1959, **17,** Mar., 57) A material called 'Ceramicite' is used.

Development of a method for roll cladding, silver, boron-carbide cermets with AISI 304 stainless steel L. Lewis and J. F. Soppet (Editors) (*YAEC*–59, 1958, May, pp. 23; from *US Govt. Res. Rep.*, 1958, Dec. 12, 635, no abstract).

High temperature coatings for chromium hot work tool steels E. B. Norris (*WADC–TR–58–269; AD–203121*, 1958, July, pp. 90; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 504) Various plated, dipped and sprayed coatings were tested and the tensile, stress rupture and fatigue properties were also observed.

Radyne-Stellite sprinkle-fuse hardfacing process (*Machinery*, 1959, **94,** Mar. 18, 610) A process in which valve and pump parts are hard-faced with stellite by filling recesses in the surface with stellite and flux in powder form and sintering by induction is briefly described.

Carbide surfacing of high-speed steel tools to increase life (*Machine Shop Mag.*, 1959, **20,** Mar., 140–143) Equipment introduced in Coventry for impregnation with hard carbide is described, and examples are given of wear-resistance produced.

Facing valve tappets with tungsten carbide Mack Trucks Inc., N.J. (*Machinery*, 1959, **94,** Mar. 11, 555–557) The cleaning, brazing, mechining, induction hardening, and electrolytic grinding processes are outlined. Hardened gear finishing is also described. Gas carburizing using cracked natural gas is employed for other parts.

A pulsed eddy current technique for measuring clad thickness D. L. Waidelich *et al.* (*ANL–5614*, 1958, July, 49, from *US Govt. Res. Rep.*, 1958, Dec. 12, 632; no abstract).

The hard-facing of Pilger rolls in tube mills O. Pejčoch and J. Kuzník (*Hutn. Listy*, 1959, **14,** (2), 173–184) [In Czech] Selection of various hard-facing alloys on the Cr–Ni steel basis with various carbon contents for the different rolls and operations of Pilger rolls is described and the best hard-facing procedure (transverse attaching of beads) explained and illustrated. Hard-faced rolls had a useful service life five times as long as the usual steel rolls.—T.G.

POWDER METALLURGY

Custom atomized metal powders G. J. LeBrasse and R. L. Probst (*Prec. Met. Mold.*, 1959, **17,** Feb., 40–41, 55) Stainless steel atomized powders are briefly noted and uses are indicated.

Furnace sintering of metals and ceramics: III R. L. Harper (*Ind. Heat.*, 1959, **26,** Mar., 498–

504) The author discusses the processes and equipment used in the sintering of ferrites, uranium oxide, and metallized ceramics. Some of the applications of these materials are mentioned.—G.F.

Compacting and sintering metal powders without the application of pressure H. H. Hausner *et al.* (*NYO*–8526, 1957, May, pp. 20; from *US Govt. Res. Rep.*, 1958, **30,** Nov. 14, 472; no abstract).

Sinterings in high stress applications (*Prec. Met. Mold.*, 1959, **17,** Mar., 29, 44) The Aero-Motive Mfg. Co. uses a sintered spring-release hub in an application in which it is required to withstand a torque of 675 lb. radial load. The sintered part gives a 90% saving in machining costs over the previously used machined part.—G.F.

Soft magnetic materials from iron powder (*Prec. Met. Mold*, 1959, **17,** Mar., 77) A new sintered armature is used in Electropact solenoid valves, replacing a machined armature with a 50% saving in manufacturing costs. Brief details are given of the design and properties of the sintered armature.—G.F.

A new basis for an inspection method for sintered metal components B. Bovarnick (*RPL* 41/2; *PB* 151133, 1958, Mar., pp. 92) Electrochemical potential measurements were made as a non-destructive testing method for sintered components. An extensive review of the theory of sintering and compaction is given and the basis for the investigation and the apparatus used are described. The values obtained are interpreted and discussed (94 refs).

FERRITES, CERMETS AND CARBIDES

Cermets – two new forms W. H. Herz (*Mat. Design Eng.*, 1959, **49,** Apr., 98–99) The spray-forming process for producing castings or for building up parts is assessed.

Phase equilibria in the ferrite region of the system Fe–Ni–O A. E. Paladino jun. (*J. Am. Ceram. Soc.*, 1959, **42,** April, 168–175).

Sintering of TiC-base cermet. II. Shrinkage of TiC–Ni compact by heating in a vacuum E. Kato and S. Naka (*Rep. Govt. Ind. Res. Inst. Nagoya*, 1959, **8,** Mar., 228–234) Gas evolution produces irregularities.

On the formation of Fe^{3+} in the system $MgO–Fe_2O_3–MgFe_2O_4$ at high temperatures L. C. F. Blackman (*J. Am. Ceram. Soc.*, 1959, **42,** Mar., 143–145) The formation of ferrous iron in the system $MgO–Fe_2O_3–MgFe_2O_4$ has a deleterious effect on the microwave performance of magnesium ferrite, $MgFe_2O_4$. The partial reduction of ferric iron in the system at relatively low temperatures as discussed in terms of the preferential diffusion of iron, and its partial stabilization as ferrous iron from lattice energy considerations.—G.F.

Investigation of the composition of an iron-rich nickel-zinc ferrite C. F. Jefferson (*AD* 102760; *MU ERI TR* 66; *PB* 132753, 1956, June, pp. 20).

PROPERTIES AND TESTS

Metallurgical research in Japan T. Mishima (*J. Met.*, 1959, **11,** Mar., 168–169) A brief outline is given of past and current Japanese work in research and development.

Investigation of leaded steels K. L. Kojola (*NGF–TR–2–57; PB* 133055, 1957, May, pp.41) The 0·15–0·35% Pb which when finely dispersed improves machineability was tested for its effect on mechanical properties.

Methods of determining surface roughness M. K. Testerman (*WADC Tech. Rep.* 58–230; *ASTIA document No.* 155828; *PB* 151268, 125, 1958, June, pp.42) Direct and indirect methods of assessment are listed and the capacitance and polarization capacitance methods are described, also tracer methods (19 refs.).

Absolute areas of some metallic surfaces T. L. O'Connor and H. H. Uhlig (*AD* 108450; *NR* 036–007, *PB* 134612, 1956, June, pp.18) Data from the gas adsorption method are given with reference to the roughness factor.

Air gauge checks crankshafts at 24 points (*Metalw. Prodn.*, 1959, **103,** Mar. 27, 537–541).

MPJ-Sheffield multi-dimensional air gauging machine for crankshafts (*Machinery*, 1959, **94,** Mar. 4, 493–494).

Ergonomic investigations into the design of master controllers R. G. Sell (*JISI*, 1960, **194,** Feb., 168) [This issue].

Ductile iron: as-cast and annealed tensile properties A. H. Rauch, J. B. Peck, and E. M. McCullough (*Mod. Castings*, 1959, **35,** Mar., 111–116) A significant relationship exists between tensile properties and Brinell hardness in as-cast pearlitic-ferritic ductile irons. However, this relationship is strongly affected by changes in composition. Prediction of the tensile properties requires knowledge of both hardness and composition. The statistical techniques used in this investigation are explained in an appendix.—T.G.

Ductility and strength of high-carbon grey irons E. M. Stein and H. O. McIntire (*Mod. Castings*, 1959, **35,** Mar., 103–110) Composition, microstructure, and inoculation effects on ductility and strength of high-carbon (3·5–4·5%C) cast irons were evaluated. Ductility decreased with increasing Mn content above 0·5%. Inoculation of low-Mn irons produced up to 50% increase in elongation, but the effect of inoculation decreased with increasing Mn content. Ductility was not affected by variation in the Si content. Increasing the Mn content above 0·5% markedly increased tensile strength. A reasonably close correlation between hardness and strength was found for all irons.—T.G.

Resistance to relaxation of spring-steel strip at room temperature V. Ya. Zubov and S. V. Grachev (*Metallov. Obra. Met.*, 1958, (5), 20–23) An experimental steel with 0·71%C, 0·51%Mn, 2·49%Si, 0·62%Cr, 0·018%P, 0·02%S, 0·006%W and 0·2%Mo was much superior to commercial steels EI142 and U10A at room temp. The quenched untempered specimens of all three relaxed much more than did tempered specimens, probably due to martensite decomposition by the prolonged action of high stress.

Elevated temperature relaxation properties of 17–7 PH stainless helical compression springs M. Clogg jun. (*Wire*, 1959, Apr., 31–35) An investigation is described to obtain relaxation data at elevated temperatures on helical compression springs made of Armco 17–7PH spring wire (condition CH), compared with that of 18Cr8Ni, Inconel 'X' and music wire springs. Effect of final hardening temperatures (17–7PH) and stress relieving temperature were examined, and data were obtained on the effect of temperature on the torsional modulus all types investigated.

Investigation of the cross-sectional deformation of carbon steels A. V. Gur'ev (*Fiz. Met.*, 1958, **6,** (4), 725–733) The coefficient of cross-sectional deformation increases with increasing stress. During a complete cycle of loading and unloading, its value falls twice intermittently to the minimum of 0·25. Explanations are suggested for this phenomenon; with an increase in the cross-sectional coefficient of total deformation the number of micro-volumes plastically deformed under a given stress increases. It is suggested that a new constant for materials should be introduced; the 'modulus of microplasticity' which makes it possible to construct hysteresis loops and determine the coefficient of total cross-sectional deformation without the need for complicated experiments.

Altered techniques for treating second grade sized ball bearing steel V. F. Isupov (*Stal'*, 1959, (6), 552) A note from the Serov Combine. Rods with surface defects are ground and magnetically sorted into grade I and sent for redrawing and into grade II which is reground and retested. Rod not grade I after three grindings is placed in grade II.

Dependence of mechanical properties of sheets on their thickness, method, and rate of cooling N. I. Vinogradov (*Stal'*, 1955, (6), 534–536) The quality of sheets 4–8 mm thick improves with an increase in the rate and degree of rolling (relative elongation). Sheets 14 mm thick and over improve by stowing in piles at 550–600°.

Reduction in the amount of rejected ball-bearing steel by means of macro-inspection V. F. Isupov (*Stal'*, 1959, (5), 461) A note on research at the Serov Combine. Defects supposed to be due to shrinkage were actually due to forging. The rejects were reduced from 5·3% to 1·8% by inspection.

Conditions of fixation of radioactive sulphur on the surface of polycrystalline iron and relationships to the crystal orientation of the metal B. Le Boucher, C. Libanati, and P. Lacombe (*Compt. Rend.*, 1959, **248,** May 4, 2578–2580) Fixation from aqueous and gaseous media at room temp. is influenced by the presence of O_2 at the surface. When the oxygen concentration is low enough the amount taken up depends on the crystalline orientation of the metal.

Stainless spring wires and spring strip K. Kayser (*Draht*, 1958, **9,** Dec., 491–496) The properties and treatments are described of the four main types of stainless steel wire – Cr, Cr–Ni, Cr–Ni–Mo, and ageing austenitic Cr–Ni steel. A brief account of the properties of spring strip is given.

Experimental study of the theory of flow C. Crussard (*Gén. Chim.*, 1959, **81,** March, 65–79) Viscous flow theory is reviewed, both in terms of rheology and in terms of dislocations.

Dislocations and the mechanical-physical properties of metal crystals F. Blaha (*Berg- u. hütten. Monats.*, 1959, **104,** June, 123–131) A lecture on the dislocation theory of metals.

The determination of residual stresses in wires H. Bühler and G. Altmeyer (*Draht*, 1959, **10,** March, 87–92) A general review of published work on investigation of residual stresses in wires is followed by a detailed account of the method of Linicus and Sachs for determining longitudinal residual stresses in wires of circular section. A modification of this method for non-circular sections is derived and applied to 'Z' sections.

Residual stresses in joists and channel beams I. V. Gunin, D. I. Piryazev, and F. R. Volchek (*Stal'*, 1959, (6), 544–546) An experimental study of residual stresses in standard sections is described. Portions were cut out and their changes in dimensions were measured. Strain-gauges were also used.

The determination of residual stresses in wire of Z-shaped cross-section H. Bühler (*Stahl Eisen*, 1959, **79,** July 9, 1005–1006) Mathematical formulæ are derived for the determination of residual stresses in wires of cross-section other than round. The formulæ are not exact but give sufficiently accurate results.

Internal stresses in cast iron H. Bühler and W. Schepp (*Giess. Tech. Wiss.*, 1959, **25,** July, 1395–1401) Specimens of various types of cast-iron including some with spheroidal graphite were studied for three-dimensional internal stresses after various cooling and tempering treatments by the trepanning and the combined trepanning and machining-off methods. Elimination of the internal stresses takes place after annealing for more than 30 min at temperatures above 300°C. It was also found that thermal cycling with high cooling rates leads to a reduction of residual stresses in the surface.—T.G.

Activity of nitrogen in liquid pure iron Y. Kasamatsu and S. Matoba (*Tetsu to Hagane*, 1959, **45,** Feb., 100–105) Results are quoted for the temp. range 1566–1740°C and N_2 pressure up to 2·3 atm in N_2 or N_2–A atmospheres. The N_2 solubility deviates positively from Sieverts' law. Equations are given for the equilibrium constant and free-energy change of the solution reaction and the activity coeff.; the last is independent of temp. in the range studied.—E.E.J.

The equilibrium between cerium and sulphur in liquid iron M. G. Frohberg (*Stahl Eisen*, 1959, **79,** Feb. 5, 162–163) A review of published information on the desulphurization of pig or cast iron by cerium. The desulphurization effect of Ce is about thousand times that of Mn, i.e. only small Ce quantities are required. Cerium, like magnesium, renders the graphite spheroidal.—T.G.

The calculation of the ultimate tensile strength of low-alloy steels V. G. D'yakov and Z. A. Abramova (*Stal'*, 1959, (6), 562–563) The formula of Mikhaelev and Gol'dshtein connecting yield-point and u.t.s. with chemical composition for commercial and normalized sheets was tested and differed from the experi-

mental values by no more than ± 3 kg/mm^2. The thickness to which the formula applies can be raised from 20 mm to 26–30 mm. The deviations were predominantly negative and a small charge in the first term is suggested.

On the theory of the strength of steels J. Němec (*Hutn. Listy*, 1958, **13**, (12), 1111–1116) Imperfections present in metals are discussed and the coalescence of fissures formed during plastic deformation to give cracks leading to fracture is considered.—P.F.

Predetermination of tensile strength in the manufacture of steel wire M. Hempel (*Draht*, 1959, **10**, March, 92–93) An abstract of a lecture given by C. Coates of Frederick Smith & Co. at Halifax Technical College, and dealing with the influence of cold work on the tensile strength of drawn wire. Causes of variability in tensile strength are discussed.

The yield point behaviour of skin-rolled and aged deep-drawing steel sheet W. Lueg and P. Funke jun. (**Stahl Eisen*, 1959, **79**, July 9, 969–976) The effect of skin passes on the ageing behaviour of low-carbon deep-drawing steel sheet was studied as a function of ageing time. It is concluded that sheet steel that has been given a skin pass ages by a combination of quench-ageing and strain-ageing. Skin-rolling is recommended for industrial application, rolls of the lowest possible diameter (e.g. 10 mm) should be used and the total required reduction should be obtained in several passes, as the deep-drawing properties are retained after ageing and skin-rolling if the total deformation was obtained by more than one pass.—T.G.

Resistance strain gauges – measuring technique H. Petrick (*Draht*, 1958, **9**, Dec., 499–504) The underlying principle, design, operation, and applications of resistance strain gauges, are described.

Delayed failure and notch tensile properties of a vacuum melted 4340 steel P. Blanchard and A. R. Troiano (*WADC–TN–58–176; AD 204791*, 1958, Sept., pp. 22; from *Nuclear Sci. Abs.*, 1959, April 15, 616) Notch ductility and notch tensile strength were increased by vacuum melting and susceptibility to delayed failure was reduced.

Fracture strengths relative to onset and arrest of crack propagation G. R. Irwin, J. A. Kies, and H. L. Smith (*ASTM Proc.*, 1958, **58**, 640–660) Methods of duplicating both plane strain and plane stress conditions in fracture strength measurements of plate containing cracks have been developed. The fracture anode may possibly be predicted in terms of plate thickness, yield stress, and fracture strength. Important practical problems may be analysed with the aid of these fracture strength values.

Correlation of tests using the congruency principle J. D. Lubahn (*ASTM Proc.*, 1958, **58**, 678–684) The principle is that fracture will occur at the same nominal stress in two different objects if the stress gradient at the notch root is the same and if the notches are congruent. The strengths were correlated in notch bend and notched disc bursting tests to $\sim \pm 8\%$. Comparison with the Griffith–Irwin theory was also made.

Elastic deterioration of bent sections and methods of avoiding it. B. Wassilieff (*Mét. Constr. Méc.*, 1959, **91**, March, 165, 167, 169) Methods of correcting this defect in the cases of U and V bends, and where a wide radius of bend is involved are described; formulæ are derived, and a nomogram for facilitating calculations is reproduced.

The torsion test with galvanized wire O. F. Holm (*Draht*, 1959, **9**, Nov., 458–459) Trials described by the author have shown that torsion tests can give a misleading picture of the properties of galvanized wire, unless the zinc coating is first stripped off by a suitable pickling treatment.

Regarding the validity of the yield point for OLK-1 STAS 1883-50 steel according to DVM A. Constantinescu and N. Lascu-Simion (*Met. Constr. Masini*, 1959, **11**, (1), 29–35) Based on a number of tests, it appears that this ferritic steel may be used with safety up to a maximum service temperature of 400°C.

Some observations on the Portevin-Le Chatelier phenomenon R. Tamhankar (*Trans. Indian Inst. Met.*, 1958, **11**, Dec., 37–53) The effect is denoted by serrations observed in the load-extension curve of Armco iron and 35 Ni–10 Cr austenitic steel when a sensitive tensile testing machine is used. Tests carried out at 20°–700°C at strain rates of 4×10^{-2} to 4×10^{5} per sec showed that in Armco iron interaction between C, N, and O atoms and dislocations were the cause of the effect whereas for the austenitic steel the interaction between partial dislocations generated by stacking faults with nickel atoms was responsible for the instability in plastic deformation. The effect is connected with blue brittleness.—A.D.H.

Properties of extruded alloys (*Prec. Met. Mold.*, 1959, **17**, May, 67) Tensile properties and hardnesses are given for carbon and alloy steels and for austenitic and martensitic stainless as extruded and after heat treatment.

Contact stresses in wire ropes A. W. Leissa, (*Wire Wire Prod.*, 1959, **34**, March, 307–314, 372) A theoretical analysis is presented of 6×7 wire rope subjected to a pure tensile load. Radial forces between strands and individual wires are expressed as a function of the tensile loading and rope geometry.—A.G.

Suitability of a static bending test for the determination of toughness of very hard steels K. Bungardt, O. Mülders, and W. Schmidt (*Stahl Eisen*, 1959, **79**, Sept. 3, 1258–1263) A static bending test is described in which a test bar of 5·5 mm in dia. is loaded in the centre. From the mean value of six to ten measurements the toughness behaviour of very hard steels, such as 90 MnV 8, can be determined with sufficient accuracy. A clear relationship exists between mechanical strength and working properties, as determined by this test, and heat-treatment. The superiority of this bond-end test as compared with an impact test is stressed and the reasons are discussed.—T.G.

Testing spring steels at elastic limit under torsion V. Ungureanu (*Lucrari Stiintifice (Cluj)*, 1958, (1), 211–216) [In Rumanian] The test parameters for spring steels are examined using the method of the elastic limit and torsion on the Giebel-Popp apparatus. It is shown that the test can be reduced to $\sim$2 min and that by measuring the residual torsion the suitability of the material can be determined at once.

Energy taken up by steel under plastic compression T. D. Shermergov (*Fiz. Met.*, 1959, **7**, (1), 146–150) With small degrees of deformation, because of the small amounts of energy completely absorbed, the relaxation processes do not play an important role. The first importance must be ascribed to the hardening of the material and to the form of the curve $\delta E/\delta \epsilon$ (where E is the absorption of energy and ϵ the deformation). For large degrees of deformation on the other hand, the deformation is accompanied by intense relaxation processes which even out the hardening processes, and the increase in the absorbed energy assumes a damped character.

Notch ductility of normalized HT8 steel P. P. Puzak (*NRL Rep.*5007, 1957, Sept. 13, pp. 14) Steels from various sources were tested and the effect of the addition of 0·08–0·12%V was investigated. Charpy V and drop-weight tests showed the high-V steels to be generally inferior to low-V steels. Variations found are discussed but limits for a 95% confidence acceptance standard are established for brittle fracture initiation in ship steels.

The dynamic yielding of a carbon steel C. J. Maiden (*Acta Met.*, 1959, **7**, May, 297–304) A criterion for dynamic yielding is developed and found to agree with the results of compressive impact tests on a medium C steel at 15°, −41°, −84°, and −121°C. Metallographic examination reveals when twinning occurs, apparently at about 125 000 lb/in^2 and this is not sensitive to temp. Tests in which yield occurred after two impacts also fitted the theory. Initial deformation of 0·2% almost eliminated the upper yield point in a subsequent impact test.

Investigating dynamical bending of steel by the deformation diagram V. G. Savitskii, K. B. Ponov, and L. A. Gaivoronskii (*Fiz. Met.*, 1959, **7**, (1), 133-136) A few hundred standard notched specimens of many types of steel were tested on the PSVO–1000 impact machine. Results are tabulated. They show that the amount of work required for destruction in dynamical bending may be greater or smaller than that required under static bending. The maximum force of the resisting specimen is always greater with impact than with static application. The yield point is a specially sensitive index to an increase in the rate of deformation.

The influence of residual aluminium on the impact strength of steel at low temperatures E. I. Rabinovich, M. K. Skul'skii, and K. K. Biktagirov (*Metallov. Obra. Met.*, 1959, (3), 25–28) Basic OH steel was used deoxidized with Fe–Mn and Fe–Si and then with Si–Ca+Al or Fe–Si+Al and supplementary Al was added to the ingot moulds. The ingots were rolled to 40 mm sheet. Specimens were quenched from 880, 920, 960, and 1 000° and tempered at 660–680°C and variously normalized or annealed. Impact strength at +20°, 0°, −20°, and −40°C was measured and Al determined spectrometrically. Grain size and Al content influence cold shortness. Al lowers the critical temp. A content of 0·02–0·03%Al is recommended.

Hugoniot equation of state of aluminium and steel from oblique shock measurement S. Katz, D. G. Doran, and D. R. Curran (*J. Appl. Phys.*, 1959, **30**, April, 568–576) An explosive-produced oblique shock was produced in a wedge specimen and measurements of shock and free-surface velocities along the wedge face gave data for the calculation of pressure and density from a single shot over a pressure range $>2:1$. The results for low-C steel are interpreted in terms of the $\alpha \rightarrow \gamma$ transition. Other data on polymorphic transitions may be obtainable.

For rough handling – these shock tests J. T. Gwinn jun. (*Prod. Eng.*, 1959, **30**, May 11, 74–77) Two tests for applying shock to components are described taking vibration into account. Packaged equipment can be tested by dropping on to a concrete floor. A half-sine variable duration impact test is also described in which a special machine is used with devices to give the desired deceleration. The mathematical analyses of these tests are presented.

Influence of cold deformation Massin (*Centre Doc. Sidér. Circ.*, 1958, (5), 1095–1106) The author discusses results obtained on deforming mild and hard steels by cold-rolling. The effect of percentage deformation on tensile strength is described and latent energy of deformation is taken into account. The relation between temperature rise of the specimen and time is represented graphically for cold-rolled and hot-rolled steels. Latent energy may be released before or after the $\alpha \rightarrow \gamma$ transformation and this energy is related to certain cold-rolling conditions.—R.P.

The influence of the temperature of plastic deformation on the structure and impact strength of austenitic steel K. A. Malyshev, G. N. Bogacheva, V. D. Sadovskii, and P. A. Ustyugov (*Fiz. Met.*, 1959, **7**, (1), 102–109) The structure and the mechanical properties of deformed specimens of austenitic steels quenched in water, inhibiting the development of recrystallization at high temperatures, was investigated at from 20–1 200°C. The diagram of the austenitic structural changes at deformation temperature is in general similar to that of polycrystalline Al and points to some conclusions concerning the mechanism of plastic deformation. At low temperatures, deformation proceeds by slipping and as the temperature increases the process changes into block formation, the deformation becoming localized at the grain boundaries. Deformation of austenite between 400–450°C gives better impact strength and hardness than cold deformation.

Direct reading polarisation-optical measuring elements for strain and stress analysis on structural members G. P. Oppel (*VDIZ*, 1959, **101**, July 11, 809–816) Two new measuring elements for determining loads on structural members are described, and examples of their use given. Based on optical polarization, the instruments measure directly extension and stress respectively; high sensitivity is obtained by superimposing phases and making use of the notch effect (11 refs).

The hot torsion test for determining the forgeability of steel G. Wallquist and J.-C. Carlén (*Jernkont. Ann.*, 1959, **143**, (1), 1–28) Twelve steels, including C and alloy steels, were tested to relate torsion to forgeability,

the number of twists to fracture, torque, and torsional work were studied as functions of steel composition, temperature, and rate of twisting. The number of twists to fracture was found to give a good indication of relative forgeability (27 refs.).

Behaviour of pure iron under impact tensile loading S. Sakui and M. Omori (*Tetsu to Hagane*, 1959, **45**, April, 415–423) Two pure irons and a low-carbon steel were tested. A peak was found in the load-time curve under impact test, apparently at the upper yield point. Yield stress and tensile strength were higher, and elongation lower than in static tests. With increase of strain rate, yield stress, and tensile strength increased. Specimens annealed at 600–700°C showed brittle fracture even after completion of recrystallization (14 refs.).—K.E.J.

The low-blow transition temperature G. M. Orner and C. E. Hartbower (*ASTM Proc.*, 1958, **58**, 623–639) A modified Charpy technique which separates the crack initiation and propagation processes. A low blow is used to initiate and a full capacity blow to propagate. The transition temperatures measured are shown to be independent of specimen size, notch geometry, and other test variables. The temperature is believed to be that at which an initiating crack can become self-propagating in a thick plate.

Early stages of fatigue phenomena in plain carbon steels M. Klesnil and P. Ryš (*Hutn. Listy*, 1958, **13**, (12), 1116–1123) An electron micrographic study of the onset of fatigue in 0·09 and 0·4%C steels is described. Irreversible damage occurs at about one-tenth the number of cycles required for fatigue failure; the latter occurring through the spread of cracks formed at the surface. Flaws within the grains were not observed. Pearlite hinders the spread of cracks and this accounts for the higher fatigue resistance of pearlitic than of ferritic steels.

Fatigue resistance of large flat components, and ways of increasing it I. V. Kudryavtsev and N. M. Savvina (*Vestnik Mashin.*, 1959, (1), 42–47) The influence of absolute dimensions on the resistance of rolled low-carbon steels is reduced according to the different conditions of loading. A specially unfavourable factor is the stress concentration occurring during contact of linked components. The influence of size is greater in relatively less pure cast steels than in the more uniform rolled steels. Surface work-hardening when stress concentrations are present is very effective both for small and for large components. For this purpose apparatus for hammering makes it possible to work-harden surfaces of steel components to a considerable depth.

Investigation into the notch-sensititivy of some types of steel under cyclic loading I. A. Oding and S. E. Gurevich (*Vestnik Mashin.*, 1959, (1), 30–35) Tests with circular cyclical bending loads are described on three types of structural steels (at various temperatures) previously notched with U, V, and hyperbolic notches with suitable radii at the base to give a stress-concentration coefficient between 1·8 and 3·43. It was found that the real stress concentration coefficient falls with an increase of the overload. From the values of the real stress concentration coefficient, within the fatigue limit, and of the overload coefficient, it is possible to calculate the effective stress concentration limit which would exceed the fatigue limit.

Scatter of resistance characteristics as depending on stress concentrations and absolute dimensions V. P. Kogaev (*Vestnik Mashn.*, 1959, (1), 35–42) From theoretical considerations of the influence of reversible stress concentrations on resistance characteristics it appears advisable that a complete probability diagram of fatigue limits be first constructed, of which examples are given. Regarding the influence of the area of cross-section, the probability diagram must be related to the stress gradient and absolute dimensions. Examples for the constructions of such diagrams are given.

Some changes in the mechanical properties of mild steel caused by fatigue stressing G. F. Modlen and G. C. Smith (*JISI*, 1960, **194**, Feb., 154–159) [This issue].

Fatigue tests on a welded chromium-molybdenum steel I. Weibull (*Jernkont. Ann.*, 1959, **143**, (1), 37–48) The relation between heat treatment before and after welding and fatigue strength was examined on a Cr–Mo steel containing 0·25%C, 1·05%Cr, and 0·20%Mo, with a filler metal of similar composition. Heat treatment after welding was found to increase fatigue strength, particularly for hardened and tempered material.

Fatigue strength of heat treated rails containing arsenic L. L. Pinkhusovich, T. S. Mar'yanovskaya, and Z. G. Fridman (*Stal'*, 1959, (4), 360–363) Fatigue strength is increased by carefully controlled quenching. An As content of 0·23% has no effect. Tests were carried out on 1·7 m specimens of R–50 type rails from 4 casts. Water-quenched rails had higher fatigue strength than oil-quenched rails.

Effect on fatigue strength of internal defects in welded joints R. P. Newman (*Brit. Weld. J.*, 1959, **6**, Feb., 59–64) Literature on the effects of porosity and inclusions on the fatigue of butt welds in mild steel is reviewed.—A.D.H.

Presentation of fatigue test results J. Strebelle (*Brit. Weld. J.*, 1959, **6**, Feb., 65–71; from *Rev. Soud.*, 1958, **14**, 24–32) Simple statistical methods are applied to the presentation of fatigue results. Three ranges of stress are considered.—A.D.H.

A study of impact fatigue strength N. N. Davidenkov and E. I. Belyaeva (*Metallov. Obra. Met.*, 1958, (9), 12–15) Further investigations confirm that endurance in impact fatigue differs from that in ordinary fatigue and is lower the less stable the steel. The differences are not due to a scale factor in specimen size.

Tentative fatigue strength reduction factors for silicate-type inclusions in high-strength steels H. N. Cummings, F. B. Stulen, and W. C. Schulte (*ASTM Proc.*, 1958, **58**, 505–514) Tests of 309 specimens of SAE4340 and 4350 steels were made and factors were estimated. These depend on inclusion size and on the hardness of the steel. Though the size ranged only from 0·001 to 0·003 in. dia. the fatigue strengths were substantially changed by the larger inclusions. It is thought that below 0·00025 in. other factors may be responsible for failure.

A fatigue failure hypothesis based upon stabilized unidirectional slip D. G. Younger jun. (*ASTM Proc.*, 1958, **158**, 576–595) The total slip process is regarded as a to-and-fro deformation superimposed on a unidirectional deformation. These are microscopic in origin and can be observed only at very high magnifications. The unidirectional process appears to cease very early in fatigue life but not until a striation pattern is estabilished. The alternating slip continues throughout until cracks are developed and propagated. Ferrous and non-ferrous tests support the mechanism proposed.

Design values for thermal stress in ductile materials B. F. Langer (*Weld. J.*, 1958, **37**, Sept., 411s–417s) Methods are proposed and discussed for the application of strain-cycling data to practical design problems involving thermal stresses. The design methods proposed are safe approximations consistent with the experimental data obtainable. A worked example applicable to a pressure vessel is given.

Relation between the dent size and density in fundamental shot-peening and the fatigue strength M. Uchiyama and K. Kamishohara (*Tetsu to Hagane*, 1959, **45**, Feb., 105–110) Reversed bending fatigue tests were made on flat specimens peened under carefully controlled conditions. Excess of impact force causes an increase of dent size and a drop in fatigue strength. There is a critical density of peening beyond which fatigue strength falls. The best results are obtained from a combination of small dents and high peening density.

The effect of tin melt on the fatigue strength of steel samples with stress concentrators M. I. Chaevskii (*Doklady AN*, 1959, **124**, (5), 1049–1051) A specially constructed apparatus was used to measure the fatigue strength of steel in various media and at elevated temperatures. The experiments with steel placed in molten tin at 300°C showed that its fatigue strength limit was doubled as compared with that of the sample in air at the same temperature. Experiments with tin plated steel samples were also carried out and the results of these experiments are discussed.—S.I.T.

Repeated thermal loads E. W. Parkes (*Tech. Tidsk.*, 1958, **88**, Oct. 14, 955–960) A theoretical development of thermal stress theory with application to alloy steels.

Thermal fatigue R. Šejnoha (*Hutník*, 1958, **8**, (10), 341–346) The nature of the failure of metals under prolonged thermal cycling at elevated temperatures is discussed, with particular reference to the prevention of thermal fatigue in tool steels by heat treatment and alloying.—P.F.

Creep testing at temperatures above 500°C using multi-specimen creep testers H. Wiegand and H. Reiner (**Metall.*, 1957, 357–361; 1958, Sept., 803–810) The construction and operation are described of two multi-specimen furnaces for creep tests up to 900°C, with or without continuous measurement of elongation. The procedure for obtaining time-elongation curves is described. Irregularities in the results obtained are attributed to factors inherent in the material. It is concluded that 20,000 h must be considered the minimum time for extrapolation to longer periods, due to inherent errors due to scatter (12 refs).

Non-uniformity of creep M. G. Lozinskii, M. B. Guterman, and E. I. Antipova (*Metallov. Obra. Met.*, 1958, (6), 6–9) Studies on local creep above and below the equicohesive temp. are reported. Microscopical observations were made during straining in a vacuum up to 1100°C at ×200. The observations are illustrated and discussed, a 12%Mo steel quenched from 1200°C and heated 2 h at 450°C being used. Points are marked for reference with diamond pyramid indentations and grain distortions are clearly recognized.

The role of automatic temperature control in creep and stress-rupture testing R. S. Day (*Ind. Heat.*, 1959, **26**, Jan., 102–108, 118) Apparatus is described, especially for turbine and jet plane forgings.

The activation energy of the process of diffusion creep in disordered substitutional solid solutions of metals Ya. E. Geguzin (**Doklady AN, SSSR*, 1958, **120**, (4), 819–822) The activation energy can be calculated from the temp. dependence of the self-diffusion coefficients, from the heat of fusion of the components and the quantity Δu_0 obtainable from the equilibrium diagram, and also from experimental determination of the effect of temp. on rate of diffusion creep. The calculations are made for some non-ferrous binary systems.

Lithoidal appearance of fractures in structural alloy steels V. D. Sadovskii, K. A. Malyshev, A. M. Polyakova, V. D. Avdeeva, I. G. Arzamastsev, and V. F. Isupov (*Stal'*, 1955, (6), 545–548) Two types of granular fracture are distinguished (along grain boundaries) during heat treatment of structural steels when heated before mechanical treatment; the hard lithoidal fracture of the first type is related to the separation of impurities (sulphides) along the austenite grain boundaries, and fracture of the second type is connected with the intragranular structure during heating and the separation of impurities during tempering with the appearance of temper-brittleness, (carbides, nitrides, phosphides). Recommendations for the avoidance of these defects are offered.

Investigations of the origins and causes of macro- and micro-cracks in ball bearing section steel I. P. Zabaluev (*Stal'*, 1959, (6), 567) A note from Dneprospetsstal. Carbide liquation appears to be the cause.

Investigation and removal of the causes of transverse cracking in ball-bearing steel ingots when heated from cold V. F. Isupov (*Stal'*, 1959, (5), 461) A note on research at the Serov Combine. Cracking occurred when ingots were charged at 350–400°C. Defects were reduced from 6·5 to 0·1–0·3% by charging cold into pits at not over 200°C.

Some considerations on the heat-checking of steel T. Fujiwara (*Denki-Seiko*, 1959, **30**, Jan., 72–96) [In Japanese] A review, covering mainly the theoretical aspects of the phenomenon (73 refs).—K.E.J.

The hardness distribution through drawn steel wires. I. T. Nishioka and Y. Yasukuni (*Nippon Kinzoku*, 1958, **22,** Aug., 412–416) [In Japanese, with German summary].—K.E.J.

A study of the influence of different factors on the results of Rockwell C tests K. F. Lindstrand (*Jernkont. Ann.*, 1959, **143,** (1), 29–35) In order to trace the cause of irregularities obtained in hardness measurements on Jernkontorets standard test blocks using standard machines, a statistical examination was made of the uncorrected hardness numbers obtained in the standard blocks with commercial Rockwell machines by different firms. No significant effect of the position of the individual impression was found, but the specific influences of test blocks, machines, and penetrators were found to be highly significant.

The micro-hardness tester 'Durimet' A. Metz (*Draht*, 1958, **9,** Nov., 460) The construction and operation of the Leitz 'Durimet' hardness tester, for loads of 15–2000 g. is described.

Hardenability bands for steels 4720-H to 50B60-H (*Met. Prog.*, 1959, **75,** Feb., 96B) Metal Progress Data Sheet. The distances from quenched end of specimen are plotted against Rockwell hardness for ten steels of this series.—T.G.

Some remarks on the theory of ageing of alloys M. Ryšavá (*Hutn. Listy*, 1958, **13,** (12), 1087–1092) The influence of shape and volume changes due to the formation of new phases on the precipitation rate is discussed.—P.F.

Correlations of brittle-fracture service failures with laboratory notch-ductility tests P. P. Puzak, A. J. Babecki, and W. S. Pellini (*Weld. J.*, 1958, **37,** Sept., 391s–410s) Bases of brittle fracture in service on various types of structure and in the case of plain carbon and alloy steels were investigated by normal laboratory notch bend tests and NRL drop-weight tests, and the nil ductility transitions determined by the latter test were shown to correlate with the service performance of all materials investigated (13 refs).

On the occurrence of mussel shell fractures Z. Eminger (*Hutn. Listy*, 1959, **13,** (12), 1141–1152) The literature on the subject is critically surveyed, and details are given of exhaustive studies carried out by the author on the effect of process technology at all stages of production on the occurrence of mussel shell fractures in Ni–V steels known to be prone to their occurrence. The formation of such fractures tends to be suppressed by all factors making for an increased solubility of gases in steel or (and) favouring a dendrite-free globular structure. The tendency to this type of fracture is much reduced by casting in a partial vacuum and by proper forging. The fractures are not a consequence of the presence of AlN, and are not induced by the uptake of H_2 during reheating on forging.—P.F.

Microstructural observations pertinent to the tempering and temper-brittleness of steel W. P. Clancy and M. R. Norton (*ASTM Proc.*, 1958, **58,** 912–931) At maximum resolution of the optical microscope the growth of ferrite grains has been demonstrated in SAE 3140 steel tempered for various times and temp. below the lower critical temp. The upper nose isothermal temper embrittlement appears to be a manifestation of the change in impact properties accompanying the normal changes in microstructure during the 4th stage of tempering. Etching practices are discussed, significant detail may be overlooked because of these.

On the temper-brittleness of steels. II. T. Nakamura (*Nippon Kinzoku*, 1958, **22,** May, 236–239) In Ni–Cr structural steel, the higher the tempering temp., the greater the lowering of transition temp. in the rapidly cooled condition. In re-heating toughened specimens, shifts of transition temp. are more pronounced near 500°C. The damping behaviour in torsional vibration of temper-embrittled and isothermally embrittled specimens is discussed.—K.E.J.

Principles of testing and evaluating the results in the study of the tendency of steel to brittle fracture T. M. Norén (*Jernkont. Ann.*, 1959, **143,** (4), 207–230) A review of testing methods from the point of view of range of application, type of specimen, and method of applying the load, and method of obtaining the results. The correlation of the results with the behaviour in service of a welded structure is discussed, with particular reference to the use of the methods as 'acceptance' and 'research' tests respectively (57 refs).

Fracture mechanism in metals, with particular reference to brittle fracture C. Schaub (*Jernkont. Ann.*, 1959, **143,** (4), 185–206) The incidence of brittle fracture in ductile materials in terms of the occurrence of high local triaxial stresses in front of a notch or propagating crack is discussed in relation to the criterion of von Mises, and the correlation between the transition temperature at the level of 1–3 kg/cm² according to Charpy V tests and the temperature below which brittle fracture may appear in practice is discussed. It was found that cohesion in a mild steel is of the order of 100–200 kg/mm² (13 refs).

Influence of order-disorder on creep of a superlattice alloy T. Suzuki and M. Yamamoto (*J. Phys. Soc. Japan*, 1959, **14,** April, 463–472) [In English] Ni_3Fe was examined and the results support the dislocation-climb mechanism. A discontinuity occurs at the critical temp. (505°C) and a remarkable acceleration of creep on disordered alloys below *Tc*. A theory is proposed, also for ordered alloys where the vacancy diffusion is thought to be anisotropic with regard to slip band orientation.

Which method for extrapolating stress-rupture data? R. M. Goldhoff (*Mat. Design Eng.*, 1959, **49,** April, 93–97) Comparison of the Larson–Miller, Dorn, and Manson-Haferd parameters is reported. At least 1000 h should be spent on testing and the best correlation of test data and the most accurate extrapolation were obtained by the Manson-Haferd method. The tests were made on S–590, Nimonic 80A, A–286, and a 1 Cr–1 Mo–0·25 V steel. The determination of the constants and comparison of the curves are explained.

Steady-state creep analysis of the weight loadings of furnace tubes on multiple supports J. L. Jacobowitz and C. K. Mader (*Trans. ASME: J. Eng. Ind.*, 1959, **81,** May, 115–125) The authors analyse creep stress–strain relationships for horizontally-supported furnace tubes, taking into account the effects of tube weight and internal pressure. Steady-state creep effects through the tube wall due to axially symmetrical heat input are also analysed. Maximum permissible tube spans are derived based on accepted criteria for creep stress and deflexions.—G.F.

Graphitization failures in piping J. B. Nuchols and J. R. McGuffey (*Mech. Eng.*, 1959, **81,** May, 43–45) Investigations following two failures of C–Mo steel pressure pipes are reported, also the repair procedure. Inspection and sampling proved difficult and replacement with 0·5%Mo–1·25%Cr was undertaken.

An investigation of the temperature dependence of the hardness of iron–molybdenum and nickel–molybdenum alloys M. G. Lozinskii and E. P. Sinodova (*Metallov. Obra. Met.*, 1959, (5), 35–40) Alloys 204 (4%Mo) and 212 (12%Mo) and Ni alloys were used; 204 remains single-phase over the whole range of temp. but 212 is 2-phase and is prone to dispersion-hardening if quenched in the single-phase state. The kinetics of ageing were worked out and the effect on microstructure is shown. The findings are discussed.

Hardenability bands for steels 8822-H to 9850-H (*Met. Prog.*, 1959, **75,** April, 96B) A data sheet giving hardenability bands for ten steels, from the AISI List, June 1958.

Hardenability bands for steels 5120-H to 51B60-H (*Met. Prog.*, 1959, **75,** Jan., 96B) Metal progress data sheet.—T.G.

The Jominy hardenability test V. Berg (*Trattamenti Termici*, 1959, **1,** March–April, 13–16) [In Italian] A description is given with the aid of diagrams of the hardenability test which enables the maker to determine the steel best adapted to his purpose in the thicknesses used.

The present state of knowledge regarding brittle fracture C. Miklosi (*Met. Constr. Masini*, 1958, *Vienna welding congress supplement*, 21–27) [In French] A review of the subject with 30 references.

The importance of dislocations at the crystal boundaries of tempered martensite for the mechanism of 'temper brittleness' A. Mašin (*Acta Met.*, 1959, **7,** March, 227–228) A letter [In German] Temper brittleness appears in Cr–Mn, Cr–Ni, and in C steels at 450–600°C without change in magnetic or electrical properties, hardness, or specific gravity. Electron microscopical studies are briefly reported on the γ-grains revealed by picric acid etching and the effect of alloying elements, diffusion, and impurity segregation and their effects on dislocations.

Present state of the problem of brittle fracture of mild steel W. Soete (*ATB Métallurgie*, 1957, **1,** (4), 115–126) The present state of knowledge is reviewed with reference to the literature, particular mention being made of the work of CNRM.

Belgian researches on the resistance of structural steels to brittle fracture O. L. Bihet (*Zváračský Sbornik*, 1959, **8,** (1), 37–49) [In Slovak] An account is given of Belgian researches carried out in recent years on the factors leading to a tendency to brittle fracture Classification by means of the Charpy impact test was found to be satisfactory.—P.F.

The effect of plastic deformation in the austenitic state on the character of the failure of 35KhGSA steel in the state of temper-brittleness E. N. Sokolkov and S. N. Petrova (*Fiz. Met.*, 1959, **7,** (2), 306–308) It may be considered as an established fact that combining plastic deformation in the austenitic state with quenching under conditions which develop reverse temper–brittleness, a repression of the characteristic temper–brittleness along the austenite grains can be noticed. This repression does not however exclude brittleness. Special investigations have shown that a steel previously subjected to mechanical and heat treatment is sensitive to the rate of cooling after tempering at high heat.

On hydrogen brittleness of steel (Report 2) I. Ohnishi, Y. Kikuta, and K. Kawai (*Osaka Univ., Fac. Eng. Techn. Rep.*, 1958, **8,** Oct., 395–404) Subjects dealt with include: kinetics of H_2 diffusion during ageing and tensile deformation, and the effects of heat treatment and pre-strain on H_2 embrittlement of mild steels. (Report 1, *ibid.*, 1957, **7,** 151–158).

Findings on intergranular absorption and a study of their relation to intergranular brittleness G. Henry, J. Plateau, X. Wache, and Gerber (*Journées d'Automne de la Soc. Française de Métallurgie*, 1958, Oct. 20–25, preprint, 7) Fractures are classified according to whether weakness is due to precipitation or to lack of cohesion. The former is much the easier to recognize. A study is now made to prove the existence of an adsorbed layer in the grain boundaries by microfractometry in nickel and iron and evidence for this is shown.

The influence of boron on the temper-brittleness of constructional steel A. M. Tarasov (*Metallov. Obra. Met.*, 1959, (5), 54–57) Boron reduces the susceptibility to permanent embrittlement even when present to the extent of only 0·003% of which is the optimum, but the tendency to reversible temper–brittleness is increased.

The anisotropy of brittle silicon sheet steel V. V. Druzhinin (*Fiz. Met.*, 1959, **7,** (2), 278–283) Experimental results confirm that anisotropy exists both in cold- and hot-rolled steel. Regarding the hot-rolled dynamo steel a direct relation was found between brittle anisotropy and texture. In specimens with structure of type (110) [100] the bending along the direction of rolling is double that transversally. In cold-rolled transformer steel specimens with normal brittleness, the number of flexures through angles between 55 and 90° is greater by a factor of 2·5 to 4 than those across the direction of rolling.

Causes of cracking of thin tinned sheet in the process of closing preserve tins J. Teindl and M. Velkoborsky (*Hutnik*, 1959, **9,** (5), 160–162) The most likely cause is shown to be the presence of cementite due to incorrect annealing procedures. Apart from the fine cementite, coarse cementite may also form at the metal surface by reaction of the metal with the CO of the protective atmosphere. Heating above Ac_3 followed by rapid cooling, is recommended to remove the cause of the cracking.—P.F.

On the cause of the cracking of steel sheet in the bottoms of the hulls of river boats O.

Ilđinský (*Zvár Sborník*, 1959, **7,** (1), 108–129) [In Slovak] On the basis of extensive work it was found that the most important cause was the notch effect arising at the edge of a weld seam.—P.F.

Experimental investigations on stick-slip sliding B. R. Singh and H. B. Mohanti (*Engineer*, 1959, **207,** April 3, 537–539) Results obtained with an analogue computer suggest that resonant vibration should be avoided to eliminate stick-slip effects but high-frequency forced vibration may be employed with advantage.

Wear of lubricated surfaces N. Chironis (*Product Eng.*, 1959, **30,** April 13, 74–75) Notes on a symposium. A tracer technique was described by V. Borsoff of Shell. Wear coefficient measurement was described by R. S. Fein of Texaco. A modified tooth profile was suggested by L. J. Collins of GEC (Lynn, Mass.) and the reduction of engine wear by additives by a team at Gulf Research. More information can be had direct from the contributors.

Friction and frictional wear B. N. Das and R. Choubey (*Trans. Indian Inst. Met.*, 1958, **11,** Dec., 67–77) Rolling wear tests on rail and tyre steel using an Amsler wear testing machine showed that the wear rate increases with load, that the coefficient of friction is independent of load but that the average rate of wear is not wholly determined by the force of friction. Work hardening of the wearing surfaces takes place and removal of the surface takes place by pitting fatigue.—A.D.H.

Scatter in the Jominy test A. Clerc (*Centre Doc. Sidér. Circ.*, 1958, **15,** (12), 2525–2531) A comparison of tests made in various works and by IRSID is made in order to determine the scatter of the results of Jominy tests, and the general tendencies observed are discussed.

On age-hardening of high-speed steel J. Ježek and J. Vobořil (*Hutn. Listy*, 1959, **14,** (1), 47–54) [In Czech] Electrolytic isolation of carbides formed during tempering between 100 and 700°C of the steel containing 0·82%C, 0·25%Mn, 3·90%Cr, 9·09%W, and 1·85%V, and their identification by electron diffraction are described. Secondary carbides form in the order Fe_4WC, W_2C, Fe_3W_3C, and VC. W_2C exists in the form of crystallographically well-defined particles even at 400°C, and cannot have a pronounced effect on hardening. Age-hardening results from the transformation of retained austenite to martensite, and from the precipitation of fibrous vanadium carbide.—

The retarding influence of phosphorus on the course of ageing of low-alloy steel after deformation by rolling F. Erdmann-Jesnitzer and W. Dehnke (*Hutnik*, 1959, **26,** (1), 1–8) [In Polish] The object of the research was to study the effect of P on the course of ageing in mild steel after deformation, promoted by C and N, and to determine whether P has a retarding influence. The effect of the chemical composition on this process is discussed and also diffusion in the Fe–C–P system. Swedish Armco iron was vacuum melted in a nitrogen atmosphere to produce mild steel casts with increasing P contents. After rolling, investigations were made of the tendency to ageing, signs of the growth in the plastic limit and in hardness, as a function of the preceding deformation and time of ageing. The tendency to ageing was found to decrease with the growth in the P content from 0·006–0·073%. On the basis of the experiments it may be said that up to a certain limiting content P in α-iron can promote a reduction in brittleness arising from natural ageing after deformation. It was also established that P retards the rates of diffusion of the atoms of the elements causing ageing after deformation.—M.T.

A contribution to the influence of vibration on structural and gauge changes and strength properties of hardened steels. J. Wyszkowski (*Prace Inst. Mech.*, 1958, **7,** (14), 89–91) A critical discussion of the above method which was proposed by E. Zmihorski for industrial application. The method uses alternating stresses by applying vibrations as a means of stabilizing the gauge or size as well as the structure of steels. These vibrations are supposed to facilitate the transformation of residual austenite into martensite. The author questions the efficiency of the method and stresses the need of further investigation of the problems involved.—F.T.L.

Hydrogen embrittlement as a cause of fracture of steel wires for concrete reinforcement W. Grundig (*Bol. ABM*, 1958, **14,** Oct., 473–515) [In Portuguese] The cause of fracture in 98% of the steel wires (0·71%C, 1·17%Mn, 0·66%Si) in the first stretch of the reinforced concrete bridge over the Guaiba delta has been found to be hydrogen embrittlement resulting from the presence of H_2S. Fractures were noticed in some wires five days after prestressing and, in ten days, all had failed. The seating for the hydraulic jacks for pre-stressing had been made with a sulphur mastic prepared by mixing flowers of sulphur, lamp black, kaolin, and motor oil, applied hot. Melting produced large volumes of gases and some of the mastic, when poured, had coated the wires in one area: these fractured first. It was also noticed that the ducts were welded with a reducing flame, causing soot deposits, and river water was used to wash them. Some water remained in the ducts for several days and some, removed for analysis, had a temperature of about 50°C. Illustrated details of the project are given. A laboratory study eliminated the quality of the steel, its external corrosion and its mild heat-treatment and the river water as possible causes. Experiments with the mastic showed that this was primarily responsible in itself and also in the gases produced, which contained H_2S, SO_2, and SO_3, and entered the ducts and the water lying therein. A study of the effects of H_2S in moist conditions was made and this showed a rapid decrease in tensile strength resulted after about 1 h exposure – leading to a 50%reduction in strength after about 4 h. The laboratory tests are reported in detail and a discussion of the embrittlement mechanism follows (35 refs.).—P.S.

Investigations of the V15/V10 ratio in hot rolled transformer sheets and influence of thickness on the magnetic reversal losses T. Brüggemann (*Neue Hütte*, 1959, **4,** April, 207–209) An outline is given of operating techniques designed to diminish magnetic reversal losses of hot-rolled transformer sheet; the influence of this reduction on the V15/V10 ratio is discussed.

Concerning plastic deformation of iron during γ→α phase transformation B. G. Lazarev, A. I. Sudovtsov, and A. P. Smirnov (*Fiz. Met.*, 1959, **7,** (1), 122–127) Pure iron of the Armco type served for investigation purposes. The specimens were heated in a special apparatus by induction with a frequency of $3 \cdot 10^6$ c/s which produced a sufficiently homogeneous heating of the surface and permitted wide variations in the rates of heating. The specimens were 0·1 mm thick, ~10 mm wide, and ~100 mm long, also cylindrical 50–100 mm long and 4–6 mm diameter. The changes of the form followed the rapid boundary displacement between the α and γ phases. The principal reasons for these changes reside in the change of volume during phase transformation and in the heat given out.

Characteristic appearances and difference between deformation by traction and by rolling: the role of grain boundaries and sub-grain boundaries A. Berghezan (*Compt. Rend.*, 1959, **248,** June 22, 3560–3561) An alloy of Al and Ag which is especially subject to precipitation was used and by this means the flow lines were revealed. Deformation by rolling is much the more complex, but in tensile deformation the effect of the grain boundaries is particularly well marked especially in the early stages.

High-range plasticity of metals beyond normal work-hardening E. V. Crane and W. S. Wagner (*Trans. ASME: J. Eng. Ind.*, 1959, **81,** May, 178–181) Plastically-worked metals have an essentially compressive 'high' working range which is beyond the point of normal tensile failure and is distinguished by a steeper or more rapid rate of work-hardening. The authors outline a testing technique designed to provide the extended plastic-range data needed for planning operation sequences.—G.F.

Fatigue properties of high-strength steels (*NBS Tech. Bull.*, 1959, April, 74–75) Retained austenite up to 10% lowers fatigue resistance and stressing converts it to untempered martensite. Four steels were tested and the importance of uniform specimen preparation was shown. Fatigue strength correlated with hardness.

Electronic unit for fatigue tests based on resonance oscillation A. Simon, St. Kovacs, O. Balint, and O. Costea (*Lucrari Stiintifice (Cluj)*, 1959, 587–601) [In Rumanian] The advantages claimed for the installation are: the frequency is theoretically infinite and can always be made to equal the natural frequency of the vibrating system; long life, small wear, hardly any repairs excepting electronic valves, noiseless operation, and universal application because in passing from the test for fatigue in bending to the test for fatigue in torsion a change in the circuit is all that is necessary. Further, invariability of deformation amplitudes, easy application, and possibility of continuous control.

Early detection of fatigue in metal alloys by ultrasonics K. Sittel (*Nondestructive Testing*, 1959, **17,** May–June, 165–170) Attenuation due to dislocations can be distinguished from other causes and used to detect fatigue damage. Effects occurring in the early stages are described and the conditions under which these can be observed are pointed out. Routine testing and choice of specimens for fundamental study are considered.

A study of the resistance to fatigue of OLC 10 Stas 880–49 steel and of nodular cast iron M. Tripa, D. Pastrav, N. Patachi, I. Pastrav, and A. David (*Lucrari Stiintifice (Cluj)*, 1959, 615–630) [In Rumanian] Results are given of fatigue tests for carbon steels and for sg cast iron at the '16th February' Railway works. Wöhler, Haigh, and Smith diagrams are constructed.

A study of the nature of fatigue damage to plain carbon steel by the reheating method T. Yokobori (*Tech. Rep. Tohoku Univ.*, 1959, **23,** (2), 91–101) A comparison is made of tests in which the specimen is annealed to remove work-hardening and in which the decrease in the endurance limit is measured. Annealing is shown not completely to repair the damage done in the early stages of fatigue. Some repair by understressing was noted, this occurs whether the understressing is applied before or after overstressing but is lost on annealing for stress relief.

The fatigue strength behaviour of a carbon steel hard chromium plated in two different electrolytes H. Wiegand and H.-R. Kaiser (*Metalloberfläche*, 1959, **13,** Aug., 249–254) The influence of an H_2SO_4 bath and the SRHS bath CR–110 developed by United Chromium Inc. of New York on layer growth and bending fatigue strength are investigated for various plating conditions (13 refs).

Fatigue strength and wear properties of salt bath nitrided gear wheels made from cast iron with nodular graphite H. Wiegand and H. Hentze (*Metalloberfläche*, 1959, **13,** Aug., 238–242) Nitriding nodular iron gear wheels is shown under favourable conditions to increase fatigue strength by 20% and to treble resistance to wear (19 refs).

Influence of repeated heating and cooling on the changes in the properties of steels and alloys S. T. Kishkin and A. A. Klupin (*Metallov. Obra. Met.*, 1959, (5), 15–19) Induction heating with air or water cooling was applied. Heating was for 2–4 sec at 550, 700, 780, and 850°C (for IKH 18 N9T stainless and alloy EI–437, 800°C). Cyclic heating gives a decrease of strength with increasing C content. Microcracks form in the rapid cooling and this is more intense the higher the temperature and the more rapid the cooling rate.

Effect of shot-peening on fatigue strength of metals. I. Effects on polished state S. Takeuchi and T. Homma (*Sci. Rep. Res. Inst. Tohoku Univ.*, 1958, **A10,** Dec., 426–434) [In English] Rotary-bending fatigue tests were made on pure iron, Si–Mn steel, 17S aluminium alloy and 40:60 brass. Shot-peening increases the endurance life several times and the fatigue strength by 3–13%. Repolishing to remove surface roughness had little effect on fatigue limit. The fatigue limit was reduced by annealing at high temp. to soften the surface layer.

Delayed failure of high strength steels A. R. Troiano (*Corrosion*, 1959, **15,** April, 207t–

212t) High strength steels plated with Cd were found to fail unexpectedly at high stress levels. The delayed fracture observed is due to hydrogen embrittlement and is enhanced by the ability of the Cd plate to prevent the escape of the H_2 introduced by pickling and plating. The kinetics of crack initiation and propagation have been studied by an electrical resistance method. An incubation period before crack initiation was found and is ascribed to the need for the H_2 concentration to build up under stress gradients at the point of highest stress. The process may be reversible. Baking treatments to eliminate H_2 are very long if coating thickness is other than small. A technique is proposed of removing the H_2 by a bake introduced when the plating is still thin.—J.F.S.

Sustained strength of steels during the study of tubular specimens subjected to internal hydrogen pressure at high temperatures N. N. Kolgatin, L. A. Glikman, V. P. Teodorovich, and V. I. Deryabina (*Metallov. Obra. Met.*, 1959, (3), 19–24) The effects of H_2 and N_2 were compared in a test rig previously described. A commercial iron and various alloy steels were used and all showed a great decrease of endurance in H_2 with inter-crystalline brittle failure. In N_2 the failure was intercrystalline and accompanied by deformation. Iron and steel 20 at 450°C showed a loss of 75–85%, low and medium alloy steels lost 22–40% at 600°C. EI579 was the best at 600°C.

Surface fatigue of carbo-nitrided steel G. W. Powell, M. B. Bever, and C. F. Floe (*Met. Prog.*, 1959, **75,** April, 88–90) It is shown that carbonitrided cases must be thick enough to withstand service-induced stresses, otherwise fatigue life is determined by the core, and is thereby reduced.

A new theory of creep A. Krisch (*Stahl Eisen*, 1959, **79,** Aug. 20, 1221–1222) The author reviews and discusses the creep theory of Oding and Geminov who take into account the number of vacancies which may lead to failure of the steel. The most favourable sites for an accumulation of vacancies are the neighbourhood of phase boundaries, grain boundaries, slip lines, and micropores. The conclusions of the Russian authors are discussed.—T.G.

Theory of creep limited by self-diffusion R. W. Christy (*J. Appl. Phys.*, 1959, **30,** May, 760–764) A mechanism of dislocation climb limited by the diffusion of vacancies from them is formulated. The activation energy for vacancy formation does not appear to be important in metals. The predicted increase in vacancy concentration in creep is too small to be observable.

Transformations of elastic deformations into residual in the case of structural transformations D. M. Nakhimov (*Metallov. Obra. Met.*, 1959, (3), 2–6) Compression of a work-hardened specimen while heated to recrystallization temp. gives a structure with equiaxial grains and a regular lattice. Below this temp. recovery is only partial. Similar phenomena are observed in tempering hardened steel. Relaxation of tempered loaded annular specimens is shown in Cr–Ni–Mo steel. Applications to straightening and the prevention of warping are noted.

Studies carried out on structural steels on the relation between experimental embrittlement temperature and type of notched test bar H. Kussmann (**Stahl Eisen*, 1959, **79,** July 23, 1065–1075) Tests were carried out on killed and rimming steels and bars of various shapes of notch. It was found that larger radius of the notch shifts the critical temperature of embrittlement to lower temperature values, and that the degree of necking is a better criterion for brittle fracture sensitivity than the impact test. The relation between brittle fracture temperature determined on a certain test-piece and that of test-pieces of different shape or even on structural parts is discussed.—T.G.

Wear and wear testing of metals A. Beneš and V. Vrzal (*Hutn. Listy*, 1958, **13,** (12), 1123–1129) Wear tests on a Savin-type machine were carried out on plain steels containing 0·2–1·3%C which had been subjected to various heat treatments, as well as on various alloyed cast irons which had been quenched at various rates. The data show that hardness is not a reliable indication of wear, the latter depending sensitively on the actual structure of the metal. Wear is plotted as a function of the circumferential velocity of the metal ring rotating on the hard metal surface, in each case for a range of normal pressures.—P.F.

Wear of carbon steel weld metal microscopical observations of the structural changed layers of the worn surface S. Ito, K. Honda, and K. Ishiyama (*J. Mech. Lab.*, 1958, **4,** (2), 49–56) Weld metal from pearlitic hard-facing electrodes was deposited on rolled mild steel plate and tested in an Ogoshi machine. A taper sectioning method was used to examine the layers produced. Oxide layers, heat transformed layers, and ruptured grain layers were distinguished. The positions of these layers and the conditions of formation are described.

Search for methods of increasing the wear resistance of parts made of high manganese steel N. P. Khetvin (*Stal'*, 1959, (5), 460) A note on research at the Hammer & Sickle works. Comparisons with imported crushing equipment parts have been made.

Magnetic properties of spheroidal graphite cast iron Y. Shinakawa and T. Miyazaki (*Sci. Rep. Res. Inst. Tohoku Univ.*, 1958, **A10,** Dec., 399–404) [In English] With the same degree of graphitization, the max. induction, coercive force and hysteresis loss of spheroidal graphite iron are lower than those of flake graphite iron, and the max. permeability and residual induction are higher. With increasing graphitization, the max. permeability increases and the other four quantities decrease.—K.E.J.

On cold-workable permanent magnet Vicalloy containing chromium T. Mishima, R. R. Hasiguti, and Y. Kimura (*Nippon Kinzoku*, 1958, **22,** Aug., 393–401) Ageing changes were studied in the air-cooled, cold-rolled alloy. The coercive force increases with decrease of saturation induction, *i.e.* with increase of pptd. vol. of non-magnetic gamma; this agrees with Néel's theory. Hardness increases remarkably in the early stage of ageing, because of the change from the disordered alpha to the ordered phase (13 refs).—K.E.J.

Some magnetic properties of present-day permanent magnet materials and their commercial uses. K. Tendeloo (*Metalen*, 1958, **13,** (15), 268–272).

Non-uniformity in the magnetic properties of cold-rolled transformer steel A. G. Petrenko, L. A. Kurtova, M. M. Petlyakov, and A. I. Belyakov (*Stal'*, 1959, (3), 267–268) Textureless fine-grained regions are found to detract from the magnetic properties. To avoid these non-metallic inclusions must be eliminated and decarburization must be carried as far as possible.

The magnetic properties of cast iron as a function of impurities, structure, and temperature A. Köniğer (*Giesserei*, 1959, **46,** April 23, 216–228) The magnetic properties of about 120 sample cast iron bars were investigated, with particular reference to the effects of form, size and distribution of graphite, and of Si content (22 refs).

A review of the underlying principles and of the properties of anisotropic ferromagnetic materials F. W. Ackermann and H. Stäblein (*Metall.*, 1959, **13,** May, 411–419) After discussing the nature of anisotropy and its causes, the properties of a number of anisotropic ferromagnetic alloys are described in detail (17 refs).

Electromagnetic inspection of winding ropes P. Teissier (*Rev. Ind. Min.*, 1959, **41,** Feb., 125–145) The principles governing electromagnetic inspection are outlined, and a detailed description and assessment of various available types of equipment are made. It is concluded that, although some useful indications are given, the quantitative data provided are inadequate.

Influence of copper on the watt losses of transformer steel S. Kronmarck (*Technik*, 1959, **14,** April, 274–276) Parallel heats were made of steels with low and normal Cu contents and rolled to cold strip. Magnetic and V_{10}/V_{15} measurements showed that for transformer steel there was no advantage in reducing the Cu content below the normal value of 0·20%.

Non-destructive testing O. Vaupel (*BWK*, 1959, **11,** April 5, 167–168) A review of recent publications (20 refs).

Measurement of the dead zone of ultrasonic pulse-echo equipment J. Koppelmann (*Materialprüfung*, 1959, **1** March 20, 110–111). The dead zone of two instruments was measured, and factors influencing the reproducibility of results in each instrument and comparability of results from different instruments are discussed.

Ultrasonic testing of wires W. Böhme (*Materialprüfung*, 1959, **1,** March 20, 111–112) The special methods used for the ultrasonic testing of wires are outlined and discussed, with reference to the range and limitations of the method recommended.

Experiences with the ultrasonic rail-testing car of the German Federal Railways W. Döring (*Materialprüfung*, 1959, **1,** March 20, 112) This rail car tester, installed several years ago, has already tested about 15,000 km of track; a brief outline of the characteristics of the equipment is given.

Present position in the field of non-destructive material testing and assessment of the results obtained E. Martin (*Materialprüfung*, 1959, **1,** March 20, 93–100) The present position of non-destructive testing techniques is discussed, with particular reference to new X-ray, gamma ray, and ultrasonic equipment. Some examples of the assessment of results are given; it is concluded that no simple rules of general application can be laid down, and tests must in many cases be supplemented by practical experience.

Review of the various methods of non-destructive testing A. de la Calle Estrada (*Anal. Mec. Elect.*, 1958, **35,** Nov.–Dec., 292–300) Methods outlined include X-ray, γ-ray, magnetic, and fluorescence techniques.

Radiographic research into the distribution of niobium in stainless steel L. S. Livshits and L. P. Bakhrakh (*Svarochnoe Proizvodstvo*, 1959, (1), 20–22) Until recently it was considered that the introduction of eight times as much Nb as C into 18 Cr–9Ni (0·10–0·12%C) steel was adequate to ensure the necessary resistance of the steel to intergranular corrosion regardless of the nature of the heat treatment employed, but now the form of the presence of Nb in the alloy is thought to be important, and its influence most favourable when it is all in the form of carbides and all the C is combined. In this article a study is made of the influence of heat treatment on the formation and diffusion of NbC by the use of the radioactive isotope ^{95}Nb, which was introduced through the electrode coating. It was found that to ensure stability against intergranular corrosion under heating conditions from 550–650°C, stainless steel with a high Nb content should be used (Nb:C$\sim$10–13). In so far as the diffusion of NbC during heating at high temperature has an unfavourable influence on the stability against intergranular corrosion of steel with a low Nb content (Nb:C$\leq$8) excessive heating temperatures (> 1200°) must be avoided. The heat-affected zones of welds which are unavoidably subjected to heating at temperatures > 1300°C will inevitably have a reduced resistance to intergranular corrosion. Considerable increase in this resistance can be obtained by heat treatment at 850–900°C for 3 h leading to the formation of NbC and thereby the exclusion of the solid solution of C. This likewise prevents the formation, at the operating temperature, of Cr carbides and a reduction in the resistance to intergranular corrosion, even in low-Nb steels. It should be noted that although the experiments were carried out on stainless steels containing Nb, the results obtained may probably also be applied to those containing Ti, though the initial diffusion temp. of Ti carbide is lower, so that the maximum heating temp. of Ti content steels should be lower.

Wear tests by the enclosed abrasive grinding method F. Klaus (*Stahl Eisen*, 1959, **79,** Sept. 3, 1293–1295) The author reviews critically the results obtained by various workers using this method which is standardized in the German DIN specifications and comments on and interprets them.—T.G.

The wheel on the rail J. C. Loach (*Rail. Steel Topics*, 1959, **5,** Spring, 18–24) Wheel form and their interaction with the rail are

considered, especially with regard to the wear of the rail head.

Demonstration of Zeiss optical measuring equipment (*Machinery*, 1959, **94,** March 25, 691–692) Items of Zeiss precision optical equipment demonstrated in London are described and illustrated. Toolmakers' and light section microscopes for examining coating thickness and surface finish are shown.

Industrial television J. E. H. Brace (*English Electric J.*, 1959, **16,** March, 32–41) An account of equipment design and present and possible future applications is given.

Focus on inspection costs pays off (*Steel*, 1959, **144,** April 27, 102–103) An optical gauge has been installed as a measuring device and for quality control in the production of sensitive pressure gauges. Savings in inspection time and costs are claimed.—A.G.

Industry practices for fluid penetrant inspection of steel tubular products (*AISI Contrib. Met. Steel*, 1959, April, pp 5) A brief description of methods and standards.

Some methods of non-destructive testing D. W. Hopkins (*Swansea Met. Soc.* [1959], pp 32) A review of penetrants, brittle varnishes, magnetic and electrical methods, ultrasonics, X-rays, and radioactive sources.

Automatic testing (*SS News*, 1959, March, 4–8) Magnetic, radiographic, and ultrasonic methods for the automatic testing at various stages of manufacture of steel parts are described and illustrated.

New soft magnetic materials and their application F. Pawlek (*VDIZ*, 1959, **101,** July 11, 816) An abstract of a paper by the above author, a full reproduction of which appears in *VDI Berichte*, 1956, (14), '*Feinwerktechnik*', and which deals with the groups of soft magnetic materials available to suit various applications.

Malleable iron, a magnetic alloy W. K. Bock (*Mod. Castings*, 1959, **35,** April, 61–68) After a discussion of magnetic theory the magnetic properties of malleable iron are presented. As a magnetic alloy, malleable iron offers the advantages of ease of casting and machining.

A semi-automatic magnetic crack detection unit MALQ for unmachined forgings C. Beck (*SS News*, 1959, March, 10–13) Details of construction and operation of the Solus-Schall MALQ unit for detecting cracks in unmachined ferromagnetic forgings are given, the article being illustrated by photographs. A fluorescent magnetic particle method is used. 800 pieces/h can be handled.

Defectoscopy of rails under magnetic fields in motion. 9. Approximate diagram of eddy currents in rails V. V. Vlasov (*Fiz. Met.*, 1959, **7,** (1), 159–160) The topography of the eddy currents in the rails depends on the method of their magnetization. The development of these currents may be represented as the addition of separate longitudinal and transversal components of the flux in motion. These are schematically drawn under a few different conditions. **9. The role of eddy currents in the formation of fields of the defects** (2), 186–191) It has been shown that in the deformation of the e.m.f. pulses, not only the defect fields induced by the magnetization of the parts, but also the fields of the eddy currents induced in the parts contribute. The critical speed has been determined below which the defects are revealed by the magnetization of the parts and above, by the eddy currents. **10. Investigating the magnetic flux in rails with different air gaps in the magnetic circuit** ((2), 319–320) The longitudinal component of the magnetic flux in the rail, within certain values of the air gap and not with very large magnetic forces, shows a maximum. The dependence of the longitudinal component of the magnetic flux on the air gap with relatively small values for the external field in motion is found to correspond to that of static field and is explained by the demagnetization of the surface of the ferromagnetic substance.

The influence of Leboite decay on the electrical properties of the iron alloys with silicon A. I. Gol'dberg, V. A. Lipatova, and P. V. Gel'd (*Fiz. Met.*, 1959, **7,** (2), 316–317) Leboite and also disilicides of Cr and Mn have semiconductor properties. Investigations have shown that the electrical properties of Fe–Si alloys are very sensitive to the phase composition of leboite and that they are different between α- and β-leboite. In view of this, and considering the very small heat conductivity of the disilicides, investigations were carried out to determine the influence of the composition on the thermo-e.m.f. of the Hall effect and on the electrical conductivity of the alloy FeSi–Si. Measurements were taken at room temperature for cast cylindrical specimens, which were annealed 4 h at 1000°C and then quenched in water.

Unilateral measurement of thickness of ferromagnetic sheets or tubes (*SS News*, 1959, March, 22–23) A description is given of the operation of a thickness gauge utilizing the Hall effect.

Principles of eddy-current testing F. Foerster (*Metal Progress*, 1959, **75,** Jan., 101–105) The principles of eddy-current testing, i.e. the impedance measurement of a coil, and its application to the detection of defects in metals, for instance cracks, as well as to hardness, tensile strength, dimensions, conductivity, and permeability measurements are explained.—T.G.

Influence of the chemical composition of the magnetic temperature ageing of iron–cobalt–nickel–aluminium alloys A. M. Morozova and F. I. Feigina (*Fiz. Met.*, 1959, **7,** (1), 40–47) Chemical composition exerts a strong influence on magnetic temperature ageing of permanent magnets in addition to its dependence on the coercive force at room temperature. Al and Ni exert the greatest influence. An increase in the Al content reduces the stability of the magnets while Ni increases it. Variations in the chemical composition of the alloy have the greatest effect on the magnetic temperature ageing during cooling.

Ultrasonic inspection of steel products (*AISI Contrib. Met. Steel*, 1959, April, pp 36) A review of methods and their application to forgings, pipes, railway wheels, blooms slabs billets and bars and plates, stainless steel products, superalloys, and tool steel.

Industry practices for ultrasonic non-destructive testing of steel tubular products (*AISI Contrib. Met. Steel*, 1959, April, pp 4) Calibration and other topics are briefly considered.

Construction of an X-ray small angle camera free from slit scattering G. Porod (*Materialprüfung*, 1959, **1,** March 20, 105–106) The design of the small angle camera developed by Kratky is described.

Regulations governing protection against ionising radiation in the use of non-destructive testing methods K. Vosseler, (*Materialprüfung*, 1959, **1,** March 20, 104) German and international safety regulations and codes for covering the use and transport of radioactive materials are summarized.

Possibilities of the X-ray diffractometric determination of the polyaxially stressed condition I. S. Szántó (*Per. Polytechn.*, 1958, **2,** (4), 275–289) The possibilities of increasing the scope of X-ray diffractometric techniques in determining factors relating to the polyaxially stressed condition are discussed, and a new apparatus is described for obviating some practical difficulties of the method by the production of X-ray deformographs

Get faster X-ray inspection with mobile carriage W. G. Hitt (*Iron Age*, 1959, **183,** Jan. 22, 64–65) A unit developed for the rapid and economic inspection of large tank welds is described. The 2 X-ray tubes are fixed on a boom, so that each can traverse half the length of the tank and expose the three lines of welding simultaneously.—D.L.C.P.

Practical application of the standardized image quality indicator used in radiography G. Chanty (*Soud. Techn. Conn.*, 1959, **13,** Jan.–Feb., 33–42) The stepped-wedge image quality indicator recently standardized in France is described in detail, and several applications of its use are discussed.

Various applications of the X-ray image intensifier H. Vogel (*Materialprüfung*, 1959, **1,** March 20, 102–103) Applications of the X-ray image intensifier to testing increased specimen thicknesses, and for quality control of large numbers of samples are outlined.

The economic and physical limits of the image quality attainable in X-radiography J. Urlaub (*Materialprüfung*, 1959, **1,** March 20, 101–102) Modifications giving improved image quality as assessed by the standard (DE) method are compared from the point of view of economics.

Determination of the depth of the decarburized zone in steel with X-rays M. D. Perkas (*Zavods. Lab.*, 1956, **22,** (12), 1458–1460) The doublet distance for martensite increases with C content so that measurement of the line separation is a measure of degree of carburization. This can be made for 0·6%C and above. Where the C is below this value the width of the (110)–(011) line can be used. Typical spectra are given and the decarburized layer can be observed.

The present position in the radiographic measurement of stresses V. Hauk (*Materialprüfung*, 1959, **1,** March 20, 106–107) The use in recent years of radiographic methods of stress measurement is illustrated by means of several examples from the literature (11 refs).

Optimum conditions of use of ^{137}Cs for the examination of welds in castings by gamma radiation M. Baimler (*Hutn. Listy*, 1958, **13,** (9), 853–862) Detailed researches by the authors on the scope and limitations of the γ-active isotopes of Cs and of ^{192}Ir are described, and the technology of utilization of these sources is outlined.—P.F.

An investigation of radioisotopes for the inspection of ship welds E. L. Criscuolo, D. P. Case, and D. Polansky (*SSC*–110, 1958, Feb., 62; from *Nuclear Sci. Abs.*, April 15, 615) Studies on Tu, Ir, Cs, and Co are reported For $\frac{1}{2}$–1 in. plate Ir is most promising.

Measurement of small vapour pressures at high temperatures. 5. Partial pressures of the components in the iron-phosphorus system A. A. Granovskaya and A. P. Lyubimov (*Zhur. Fiz. Khim.*, 1953, **27,** (10), 1443–1445) A tracer study using ^{32}P is described, the weight of iron being obtained by difference. The state of combination of the P is discussed and heats of sublimation were computed as well as heat of solution, which corresponds to iron phosphide formation.

The density of iron-carbon alloys in the liquid state L.-D. Lucas (*Compt. Rend.*, 1959, **248,** April 20, 2336–2338) The range up to 17·2 atomic %C from 1300–1600°C was covered by a bubble pressure method.

The properties of steel at elevated temperatures: (review of literature published during 1957) A. Krisch (*Stahl Eisen*, 1959, **79,** July 23, 1080–1083) The review covers: tensile testing at elevated temperatures, hot hardness, creep equipment and creep testing and the effect of multi-axial stresses and notch effects (69 refs).—T.G.

Stress-rupture properties of malleable iron at elevated temperatures L. C. Marshall and G. F. Sommer (*ASTM Proc.*, 1958, **58,** 733–752) Ferritic and pearlitic irons were tested for up to 2300 h at 800–1200°F, and only ductile properties were observed with small likelihood of transitions or structural changes. A new least-squares method of computing Larson-Miller plot parameters is derived. A high level of performance is to be expected from ferritic malleable irons at 800–1200°F with an anomaly in low-C ferritic material which has unexpectedly high strength at 800°F. These irons are superior to the unalloyed cast irons with which they are often compared and equal to a number of alloyed materials.

Influence of the purity and the structural state of iron on its capacity for occluding cathodic hydrogen S. Besnard and J. Talbot (**Rev. Mét.*, 1959, **56,** Feb., 163–170) Zone-melted Fe occludes very small amounts of H_2, and polygonized Fe occludes less H_2 than non-polygonized specimens. Addition of Na_2S to the electrolytic bath increases occlusion of H_2; autoradiographic examination using the isotope ^{35}S has shown the intergranular penetration of this element.

Diffusion and solubility of hydrogen in iron and in dead-mild steels J. Plusquellec, P. Azou, and P. Bastien (*Compt. Rend.*, 1959, **248,** March 23, 1816–1819) The influence is examined of a preliminary cold-working both at ambient temperatures and the temperature of liquid air, on the solubility of hydrogen in a steel containing 0·08%C. The coefficient of

diffusion was also determined at 20°C, using spherical specimens.

On the function of nitrogen as an alloying element in heat-resisting materials. II. Ageing of 16–15–6 type alloys M. Okamoto, R. Tanaka A. Sato, and T. Ishizuka (*Tetsu to Hagane*, 1959, **45**, April, 423–432) Results are given for Timken 16 Cr–15Ni–6Mo and —7·5 Mn. The max. N_2 addition was found to be 0·3%. Solution-treated alloys during tempering showed pptn. (of nitrides and carbides) at 500–600°C and above 800°C. N_2 addition increased hardness. 13–17%Ni had no effect on ageing characteristics. C up to 0·15% promoted age-hardening but caused rapid softening with long heating (27 refs).—K.E.J.

Contribution to the metallurgy of austenitic Cr–Mn and Cr–Mn–Ni steels alloyed with nitrogen F. Pobořil and M. Zezulová (*Hutn. Listy*, 1958, **13**, (11), 969–976) The solubility of N_2 in the steels was found to increase with decreasing temperature. Additions of N_2 in excess of the solubility results in the formation of blowholes in ingots and castings.—P.F.

The solubility of nitrogen in solid iron in the presence of vanadium and chromium M. G. Frohberg and H. Graf (*Stahl Eisen*, 1959, **79**, March 5, 304–306) A review of a number of papers on the solubility of N_2 in Fe–Cr solid solutions is given. According to the equilibrium diagram the γ-phase is unstable at all temperatures, but it has been found that it becomes stable in the presence of N_2, the stabilization is obtained at very small N_2 levels.—T.G.

The effect of selenium on the machinability and tensile properties of 5% chromium steel F. W. Boulger (*Trans. ASM*, 1959, **52**, preprint 131, 18) 0·05%Se improved machinability 8% on annealed samples and >50% on bars heat-treated to 330 Brinell. Se or S up to ~0·22% had no effect on tensile properties of annealed samples or on samples heat-treated to ~278,000 p.s.i. but ductility of transverse specimens at this strength level was reduced. This effect was not observed up to 0·18%Se with normal S content.

A further contribution on the structure of high-temperature austenitic steels M. Pobořil and M. Zezulová (*Hutn. Listy*, 1958, **13**, (12), 1061–1069) The validity of various formulae giving the Ni and Cr equivalents of other alloying elements present in austenitic stainless steels were tested, particularly in relation to the predictions of the amount of ferrite retained in such steels. It is shown that in the equations of the equivalents derived it is necessary to substitute not the weight percentages of the other alloying elements, but the respective activities.—P.F.

Influence of phosphorus and arsenic on the parameters of the crystal lattice and hardness of alpha-iron V. N. Svechnikov, V. M. Pan, and A. K. Shurin (*Fiz. Met.*, 1958, **6**, (4), 662–664) Electrolytic iron remelted *in vacuo* (10^{-4} mm) was the base for Fe–P and Fe–As alloys. Other constituents were 0·02%C; 0·0009%Mn; 0·017%Si; 0·023%S; and 0·0032%P. An increase in the P content from 0 to 2·8% resulted in a decrease of the lattice parameter of the α-iron from 2·8607 to 2·8563. An increase of As. from 0 to 12·4% resulted in an increase of the lattice from 2·8607 to 2·8800. Curves of the macro- and microhardness of the α-iron as a function of P and As contents are plotted.

Effect of molybdenum on carbon content and hardness of case-hardened steels H. U. Meyer (*Stahl Eisen*, 1959, **79**, May 28, 818–821) An extension of previous work. Mo contents of 0·5% do not show an increased uptake of carbon in case-hardening. This finding is in agreement with the results obtained in previous studies. It was found, however, that Cr steels show lower hardness than all other steels used in this study.—T.G.

Effects of aluminium on the properties of iron–chromium–nickel–manganese alloys K. V. Gorev and L. I. Shvedov (*Inzhener. Fiz. Zhur. Akad. Nauk. BSSR*, 1958, **1**, June, 45–49; from *Nuclear Sci. Abs.*, 1959, **13**, Mar. 31, 508) Alloys with >12%Ni and >3%Al had tendencies to dispersion hardening and increased heat resistance.

Influence of manganese and molybdenum on carbon solubility in alpha-iron and the kinetics of the carbon elimination from the alpha-iron in the presence of manganese and molybdenum S. N. Polyakov and K. F. Starodubov (*Fiz. Met.*, 1958, **6**, (6), 1110–1121) Investigations were carried out by means of internal friction between 720° and 550°. 0·75%Mn and 0·4%Mo reduce the solubility of carbon in α-iron. The solubility curve showed that with 0·75%Mn the relative amount of the phase separating between 650° and 550° is greater than in pure iron. The kinetics of carbon elimination from the solid α-solution are different for Mn and for Mo. With Mn an incubation period occurs, with Mo no incubation period appears.

High temperature effects of boron in iron and iron alloys R. M. Goldhoff, J. W. Spretnak, and R. Speiser (*AD* 90913; *AF WADC TR* 55–281; *PB* 134641, 1956, Mar., pp.62) High purity iron and alloys with and without B were tested for grain growth, properties and structure.

Serviceability of boron steel components R. E. Fish (*PB* 133529, 1957, Feb., pp.46; from *US Govt. Research Reports*, Oct. 17, 1958, **30**, (4), 250) [No abstract given].

Effect of boron on the relative interfacial tension of gamma iron A. M. Adair, R. Speiser, and J. W. Spretnak (*AD* 40743; *AF WADC TR* 54–150; *PB* 134515, 1954, Apr., pp.26) Thermal etching studies were made on two commercial steels. B reduces interfacial tension and C in the range 0·2–0·4% does not affect this reduction.

Investigation of the mechanism by which boron increases the hardenability of steel C. R. Simcoe, H. J. Hucek *et al.* (*AD* 65275; *AF WADC TR* 54–542; *PB* 133819, 1954, Dec., pp.69) B decreases the nucleation of ferrite and bainite. Because of its atomic diameter it collects at lattice imperfections with decrease of energy at these sites. The critical amount for SAE 8635 steel is 0·0004%B added to fully deoxidized steel. Hardenability was reproducible over the range 0·00005–0·0017%B.

Effects of rare-earth additions upon the mechanical properties of two experimental gun steels R. E. Boni and D. C. Buffum (*WAL R* 310/211; *PB* 134742, 1957, Aug., pp.28) Rare earth metals generally cause increased impact strength at the transition temperature, greatest with bainite–martensite structures. The increase was greatest in the transverse direction.

Effect of rare-earth additions on stainless steel melting variables R. H. Gautschi and F. C. Langenberg (*Ind. Heat.*, 1959, **26**, Mar., 538) Brief details are given of the effects of rare-earth elements on grain size, structure, sulphur content, and inclusion content of stainless steel ingots.—G.F.

Determination of the cerium habit in SAE 1035 steel R. H. Singleton (*WAL R* 310/190; *PB* 132180, 1956, Nov., pp.137) Ce was added immediately before or during teeming and the amount, nature and dispersion of Ce and its compounds were examined.

Development of cast iron-base alloys of austenitic type for high heat-resistance and scale-resistance F. Eberle, W. E. Leyda *et al.* (*AD* 90691; *AF WADC TN* 55–290; *PB* 134476, 1955, Oct., pp.73) The most promising alloy had 0·52%C, 1·11%Mn, 0·7%Si, 19·8% Cr, 27·8%Ni, 2·02%Nb, 0·63%Ta, 2·2%W and 0·05%Ce + La.

Four high-strength mild carbon steels (*Mat. Design Eng.*, 1959, **49**, Jan., 116–117) The Great Lakes Steel Corp. announces the development of four new high-strength mild carbon steels of the GLX–W series. The steels are Nb-treated and consequently very fine grained, resulting in high yield strength, UTS and toughness.—T.G.

How to select a stainless steel J. L. Everhart (*Mat. Design Eng.*, 1959, **49**, Jan., 95–110). Manual no.155 As no single grade of wrought stainless steel is satisfactory for service under all conditions, the author discusses the selection of a suitable grade under the headings: corrosion- or heat-resistance, mechanical and physical properties, ease of fabrication, availability, and price. The paper contains many graphs, tables, lists and illustrations.—T.G.

High strength at 1400°F claimed for precipitation-hardening steel (*Mat. Design Eng.*, 1959, **49**, Jan., 120–124) A new precipitation-hardening steel that maintains its high strength and corrosion-resistance up to 1400°F has been developed by Universal-Cyclops Steel Corp. and called Unitemp. 212. Composition 0·05–0·15%C, >0·50%Mn, >0·50%Si, 15–17%Cr, 23–27%Ni, ~4%Ti, >0·5%Al, 0·3–0·9% Nb+Ta, 0·005–0·10%B, 0·02–0·09%Zr, >0·04%S, and >0·04%P. Tensile, low-temperature, and physical properties and heat-treatment are shown in tables.—T.G.

High strength, low alloy steels for special uses (*Mat. Design Eng.*, 1959, **49**, Feb., 125) Three new grades are announced by Kaiser Steel with a table of composition and properties and a brief account of uses.

High-strength steels for aircraft applications A. J. Lena and E. E. Reynolds (*Blast Furn. Steel Plant*, 1958, **46**, Oct., 1081–1088, 1097) A review is given of the present status of high-strength steels for aircraft applications – both for airframes and jet engines – with particular emphasis on recent developments in the following fields: (i) alloys and heat-treatment; (ii) manufacturing methods; and (iii) testing.

Stainless steel (*Engineer Foundryman*, 1958, **24**, Dec., 49–50) The properties of some typical stainless steels are listed and substitutes for Ni are considered. Recommended uses of stainless steel include railway coach construction.

Stainless steel as a structural material I. L. G. Baillie (*Engineering Materials and Design*, 1958, **1**, Nov., 92–95; Dec., 145–147) Heat treatment and mechanical welding, corrosion and other properties of four classes of stainless steels are given. The two grades FV448 and FV.FDP are further considered for their suitability for use under various conditions.

Classifying the precipitation hardening stainless steels (*Ind. Heat.*, 1959, **26**, Mar., 532–538) In this article, the different types of precipitation-hardening stainless steels are discussed, and classified according to microstructure in the solution-treated and aged conditions. Group 1 steels are martensitic in both conditions; Group 2 are austenitic as solution-treated but martensitic when aged; and Group 3 are austenitic in both conditions. A possible fourth group is that of steels with a duplex austenite-ferrite structure in both conditions.

Evaluation of chromium–manganese–nickel stainless steel W. F. Emmons (*NAM AML AE* 1001; *PB* 132817, 1956, Apr., pp.26) A 17%Cr, 8%Mn, 4%Ni steel high in N_2 was tested for tensile, stress-rupture and impact properties as a replacement for 18–8 steel.

A new precipitation-hardening stainless steel A. C. Gilbraith (*Met. Treatment*, 1959, **26**, Mar., 91–94) An account of PH 15–7 Mo and its properties in the annealed and cold-rolled state is given. The sub-zero hardening process and its effects are also mentioned.

Three new alloys beat heat, nuclear barriers (*Chem. Eng.*, 1959, **66**, Feb. 23, 168, 170, 172) Armco-22–4–9 stainless steel, Jones and Laughlin carbon steels which do not retain radioactivity with 0·1%Mn, 0·2%Si, 0·2%Ti, 0·1%Al and 0·2%C, and Fe–Al–Mn alloys developed by the National Research Corp. are briefly described.

On the recent high-tensile steels. I. M. Yamaki (*Tetsu to Hagane*, 1959, **45**, April, 438–450) A review of properties.—K.E.J.

Recent trends in research and its application to super-strength structural steels C. Asada and M. Yasuda, (*Denki-Seiko*, 1959, **30**, Jan., 36–56) [In Japanese] A review, covering mainly the physical and metallurgical properties of a large number of alloy steels (22 refs).—K.E.J.

Study on 17–7–PH stainless steel. I. On the mechanical properties of this stainless steel containing about 0·7% Al T. Sato and T. Furukawa (*Nippon Kinzoku*, 1958, **22**, May, 253–257) The M_s point is below zero, and hence martensite is not formed by normal heat-treatment. Austenite is hardened remarkably by cold work, more so than in 18–8 steel. The best mechanical properties were obtained by ageing in the range 450°C for 8 h to 500°C for 1 h (13 refs).—K.E.J.

Evolving new low-alloy, high strength casting and rolling steels for wagons and chemical plant constructions N. F. Dubrov (*Stal'*, 1959, (6), 566) A note from the Ural Research Institute for Ferrous Metals. 17 Kh GSL steel with 0·13–0·2%C, 1·2–1·6%Mn, 0·3–0·6%Si, 0·3–0·6%Cr, and 0·15–0·4%Cu, and 14G2 with additional Ti or V were examined. Their properties are outlined.

High speed tool steels H. Briefs (*Metalen*, 1959, **14**, May 30, 150–156) [In Dutch] This article is a review on the development and the present position regarding the optimal hardness and special treatments of high-speed steels, the further development and dimensional stability of die steels, steel dies for the plastic industry with special reference to materials for hobbing; the hobbing process is considered. To conclude, attention is given to martensite hot-work steel and its behaviour with time. Numerous graphs and tables appear in the text, all of which seem to have been drawn from German sources (16 refs).—F.R.H.

Nitridable steels free from molybdenum M. B. Pridantsev, G. L. Livshits, and G. A. Torpanova (*Stal'*, 1959, (3), 262–267) The development of three steels is described and their properties are given before and after hardening. Al was kept low, simplifying production and improving mechanical properties. All three have 0·35–0·43%C, 0·17–0·37%Si, 0·2–0·4Mn, and 1·5–1·8%Cr. 38HUA has also 0·5–0·8%Al, 38HVFUA has 0·40–0·7%Al, 0·2–0·4%W, and 0·1–0·2%V and 38 HVUA has the same Al and W but no V. Heat treatments are recommended and uses are indicated.

High boron alloy steels (*Stal'*, 1959, (3), 269–273) A review of the foreign literature.

New developments in the field of materials containing nickel (*Metall.*, 1959, **13**, May, 420–427) A general outline is given of the compositions and properties of structural and other steels with Ni as an alloying addition. Other ferrous applications include wear-resistant and austenitic cast irons, and low-expansion Ni–Co–Fe alloys.

Two new superalloys excel at elevated temperatures E. E. Reynolds and R. K. Pitler (*Iron Age*, 1959, **183**, Jan. 22, 70–71) The composition and properties of two new alloys are described; they are precipitation hardening alloys which are finding increasing applications in the high temperature field. D–979 has an Fe–Ni–Cr base; AF71 is an Fe–Mn–Cr based alloy with a lean alloy content. Both grades can be produced in billet, bar, wire, sheet, strip, and foil forms.—D.L.C.P.

Development of research in a large Italian iron and steelmaking group. Its technical and human problems and the influence of the thought of Henry le Chatelier A. Scortecci (*Rev. Mét.*, 1959, **56**, April, 317–323) The author describes the development under his direction of an Italian research and information centre, and gives an idea of the nature of the problems solved.

METALLOGRAPHY

The accuracy of point counting in metallographic investigations T. Gladman and J. H. Woodhead (*JISI*, 1960, **194**, Feb., 189–193) [This issue].

The appraisal of microstructure of heat-treated high-speed steel E. Kunze (*Stahl Eisen*, 1959, **79**, Feb. 5, 145–148) The degree of tempering of heat-treated high-speed tool steel cannot be judged – as is often assumed – from the appearance of the grain boundaries in metallographical sections as it depends on a number of variables such as etching technique, steel composition, and thermal history.—T.G.

Use of an electrolytic plug in electron microgaphy P. A. Jacquet and E. Mencarelli (*Rev. Mét.*, 1959, **56**, Feb., 129–142) The application of the electrolytic plug for the local polishing of metallographic specimens is described, and examples of its use are given, one of which is on a ferrous specimen.

Non-destructive technique for the electron microscopical study of fracture surfaces. E. Mencarelli and P. A. Jacquet (*Compt. Rend.*, 1959, **248**, April 27, 2477–2479) A method of nitrocellulose replica formation which is covered with vaporized C and dissolved away leaving the C replica is described. Surfaces of mild and ultra-mild steel breakage faces are shown.

Polishing with the 'Ellopol' Apparatus P. A. Jacquet (*Mét. Prog.*, 1959, **75**, Jan., 125–126) A portable electropolishing apparatus, called the Ellopol, employing a hand-held electrode is described and illustrated. A micrograph of a 18:8 stainless steel is shown, polishing required 60 sec and etching 10 sec.—T.G.

On the method for revealing the austenitic grain size in steel Y. Imai and H. Hirotani (*Tetsu to Hagane*, 1958, **44**, Dec., 1393–1407) A review, with 57 references.—K.E.J.

Studies on composition and process of formation of non-metallic inclusions in steel ingots T. Ao and T. Tokuda (*Tetsu to Hagane*, 1958, **44**, Dec., 1360–1365) Scum patches are produced by corrosion and spalling of runner bricks. Aggregates of α–Al_2O_3 are produced by oxidation of the deoxidizer during pouring. Non-metallic inclusions in bearing steel are mainly spinel, with a little α–Al_2O_3 and quartz.—K.E.J.

A new method of determining the number and size distribution of spherical particles in metal samples S. Drápal and V. Horálek (*Hutn. Listy*, 1958, **13**, (12), 1105–1111) A simple statistical method is developed for determining the particle size and distribution in the metal from data obtained from metallographic planar sections. A log-normal size distribution is assumed.—F.F.

Non-metallic inclusions in ball-bearing steel P. M. Danilov (*Stal'*, 1955, (6), 522–525) The formation of complex silicate inclusions in the ingots of ball-bearing steel is related to the deoxidation process occurring during crystallization. It is inhibited at relatively low pouring temperatures and also by the presence of measurable quantities of Al, or other no less powerful deoxidizers. Under conditions obtaining at the Kuznetsk Metallurgical Combine (where this study was carried out) a temp. of 1540–1560° is recommended with a residual Al% of approximately 0·02% (silicate and metallic). To avoid contamination by silicate impurities a method must be evolved of introducing Al into the mould during siphon casting (or in the ladle after tapping, but with shielding of the metal jet from oxidation).

Study of carbides in steel O. Gautsch and H. Sundermann (*Stahl Eisen*, 1959, **79**, May 14, 726–729) The authors review critically and comment on the work of N. H. Popova, published in Moscow 1957. Electrochemical isolation and differential analysis are dealt with separately.—T.G.

The influence of heating and cooling on the precipitation of aluminium nitrides in low-carbon steels and on their mechanical properties E. S. Levinson (*Stal'*, 1959, (6), 563–566) A review of recent foreign literature.

Determination of spherical inclusions in ball bearing steels I. P. Zabaluev (*Stal'*, 1959, (6), 567) A note from Dneprospetsstal. Preliminary work on isolated inclusions suggest the black type to be FeO and the glassy type to be impure Al silicates.

The precipitation of carbides and nitrides during tempering of low carbon 12%Cr steels J. Koutský and J. Ježek (*Hutn. Listy*, 1958, **13**, (12), 1098–1105) Electron diffraction and electron microscopy were used in researches confirming the occurrence of Kuo's (*JISI*, 1953, **160**, 233) carbide reactions in the decomposition of martensite. The formation and orientation of Cr_2N were studied. Small amounts of N_2 suffice for the formation of this phase below Ac_1, and may be the cause of the embrittlement of such steels during high-temperature service.—F.F.

Study of the microsegregation of arsenic and copper by the autoradiographic technique, and quantitative examination by the Castaing microprobe C. Crussard, A. Kohn, C. de Beaulieu, and J. Philibert (*Rev. Mét.*, 1959, **56**, April, 395–406) Investigations carried out by IRSID have shown the existence of high local interdendritic concentrations of As; also the fibrous rolled structure generally attributable to P+S can also be caused by As. Tests in Cu segregation have also been made (11 refs).

Structures – the impact of modern metallurgy A. G. Quarrell (*Structural Eng.*, 1959, **37**, Feb., 31–39) A brief account of metallographic structures and metal physics conceptions with an account of the properties of the high-tensile structural steels and other alloys.

The physical chemistry of metallic solutions and intermetallic compounds (*NPL Symposium No. 9, held June 1958 at Teddington*, 1959, 2 vols). **Calorimetric methods for the study of metallic systems** F. W. Wittig (paper 1A, pp.19) Types of calorimeter, characteristics and methods of use are reviewed (121 refs.). **Experimental equilibrium methods at high temperatures** J. Chipman, J. F. Elliot, and B. L. Averbach (paper 1B, pp.27) Methods of investigation of gas–metal systems, vapour pressure measurements, electrical measurements, and phase distributions are reviewed (93 refs.). **Electrical and magnetic measurements on alloys** B. R. Coles (paper 1C, pp.14) Resistivity measurements and other electrical and magnetic studies are reviewed (55 refs.). **X-ray measurements of electron density distribution** W. H. Taylor (paper 1D, pp.8). **Measurement of the surface tension of metals** P. Kozakevitch (paper 1E, pp.11) Methods are listed and briefly surveyed (42 refs). **Viscosity and density measurements of molten metals** G. Urbain (paper 1F, pp.13) A brief review (75 refs). **A high-temperature calorimeter for slow reactions** O. Kubaschewski, W. A. Dench, and V. Genta (paper 1G, pp.8) Heats of reactions which go to completion in ~ 2 h below 1000°C can be measured with a precision of ~ ± 100 cal/g atom of alloy. **A diphenyl ether calorimeter for measuring high temperature heat contents of metals and alloys** R. Hultgren, P. Newcombe, R. L. Orr, and L. Warner (paper 1H, pp.8). **The measurement of contact angles between liquid and solid metals** D. H. Kerridge and S. D. Ford (paper 1I, pp.8) A modified vertical plate apparatus for measurement of receding contact angles is described. **Soft X-ray emission spectra** J. A. Catterall (paper 1J, pp.4). **Thermodynamics and models of metallic solutions** R. A. Oriani (paper 2A, pp.14). **Structure of liquid solutions** K. Niwa and M. Shimoji (paper 2B, pp.15) Mainly thermodynamical (61 refs). **Electrolytic transport in metallic solutions** T. Heumann (paper 2C, pp.13) Non-ferrous. **Short range order and thermodynamic properties of metallic solutions** A. Munster and K. Sagel (paper 2D, pp.14). **Some problems in the theory of dilute solutions in metals and binary alloys** C. B. Alcock (paper 2E, pp.11) The chemical bond and free electron approaches are discussed. It appears that ion–ion interactions must be included in the latter. In ternary solutions the former approach seems more fruitful for the calculation of thermodynamic properties. **The solubility of iron–nickel alloys in liquid lead: 700°–1100°C** B. Fleischer and J. F. Elliott (paper 2F, pp.12) Activity coefficients are computed. **Interpretation of the thermodynamics of liquid metallic solutions** M. Shimoji (paper 2G, pp.10) A statistical theory treatment. **On miscibility in liquid alloys** J. H. O. Varley (paper 2H, pp.7) A model for the calculation of misfit energy is advanced for solutions of metals with atoms of different volumes. **Energetics of dilute solutions of noble metals in liquid tin** R. A. Oriani and W. K. Murphy (paper 2I, pp.10). **Electronegativity of metals and certain properties of metallic solutions** A. F. Kapustinskii (paper 2J, pp.5). **Electrolytic transport and conduction mechanism in iron and nickel** H. Wever (paper 2L, pp.8) Apparatus is described and an account is given of measurements on Fe and Ni in which the general direction of movements were looked for. **Crystal structure and bond mechanism of intermetallic phases** G. V. Raynor (paper 3A, pp.19). **Relations between physical properties and bond mechanisms of intermetallic compounds** O. Kubaschewski and H. A. Sloman (paper 3B, pp.13). **The problem of the stability of intermetallic phases** O. Kubaschewski (paper 3C, pp.12) Some iron compounds are included. **A study of structural variations of close-packed phases** K. Schubert (paper 3D, pp.8). **Crystal structure and bond mechanism** H. Nowotny, F. Holub, and A. Wittmann (paper 3E, pp.10). **Solid solutions of metallic compounds** I. I. Kornilov (paper 3J, pp.8) A few ferrous systems are mentioned. **(Volume II) Phenomena accompanying solid-liquid transformations of metals and alloys** A. Schneider and G. Heymer (paper 4A, pp.18). **Thermodynamics and kinetics of solid-state transformations** U. Dehlinger (paper 4B, pp.16) Dislocation theory and free energy calculations. **Measurements of the viscosity of undercooled molten metals** G. Cavalier (paper 4D, pp.11) Iron is included. **Densities of molten silver, copper and iron** G. Urbain and L. D. Lucas (paper 4E, pp.10) Densities and coefficients of thermal expansion were determined in apparatus shown. The values are

compared with previous determinations. **Studies of the early stages of diffusional precipitation in alloys** G. Borelius and L. E. Larsson (paper 4F, pp.11). **Nitrogen and hydrogen in iron and steel** L. S. Darken (paper 4G, pp.11) N_2 is considered as an interstitial constituent, as a component of precipitates, as gas in voids or blisters and associated with Al and other foreign atoms. Hydrogen has high mobility and interacts with dislocations and also occurs in voids and cracks. Physico-chemical and mechanical behaviour are discussed. **High temperature enthalpy of gamma and delta pure iron.** M. Olette and A. Ferrier (paper 4H, pp.11) Calorimetric measurements on 99·97% Fe are reported. The heat of transformation obtained was 275 cal/g-atom at 1395°C. **Thermodynamical calculations of phase diagrams** J. L. Meijering (paper 5A, pp.20). **Thermodynamic principles in the refining of metals** F. D. Richardson (paper 6A, pp.23) Various data on Fe are included including deoxidation by Mn. **A thermodynamic study of iron sulphide–iron oxide melts** S. Bog and T. Rosenqvist (paper 6B, pp.7) Equilibration of the melt with a H_2–H_2S–H_2O mixture in an Al_2O_3 tube was examined. Activities are obtained. **The solubility of nitrogen in 18 : 8 stainless steel** E. T. Turkdogan and S. Ignatowicz (paper 6C, pp.8) Measurements at 1000–1300°C were made. Ni reduces N_2 solubility, the effect decreasing at higher temperatures. **Activity of silica and alumina in molten CaO–SiO_2–Al_2O_3 slags** K. Sanbongi and Y. Omori (paper 6D, pp.10) Reversible cells were set up and e.m.f. measurements made. **An analysis of the carbon elimination process in the open-hearth furnace** R. G. Ward and N. Birks (paper 6E, pp.10) The transfer of oxygen to metal from slag is rate controlling. Factors governing the transfer are discussed and the great importance of the interface is shown. **Significance of non-stoichiometry in metal compounds** J. S. Anderson (paper 7A, pp.29) (131 refs) Each section is followed by discussion. The remaining papers (2K, 3F, 3G, 3H, 3I, 4C, 5B, 7B) are purely non-ferrous.

An interference microscope with a wide range of applications (*Machinery*, 1959, **94**, Mar. 11, 561–563) A microscope developed in Western Germany is described. It is used primarily for the examination of surface finish. Direct observation shows finishes from 40–1 microns, and multiple-beam interferometry shows 0·5 microns. Surfaces not directly accessible are measured by replica methods in a Zehender chamber. The Sabatier method of processing the film sharpens the band definition.

Development of techniques associated with the use of the electron microscope to determine the structures resulting from various subcritical thermal treatments of unalloyed low carbon steel A. Revere (*A D* 100368; *PB* 132748, 1955, Oct., pp.320) The one-step and two-step replica techniques were examined for application to steel structures and the most faithful reproduction of very fine grain boundaries and the carbides in these and in the ferrite matrix was sought.

The comparative merits of different methods of microradiography V. E. Cosslett (*Appl. Sci. Res.*, 1959, **7B**, (5), 338–344) Instead of exposure time the total time up to production of the magnified image for visual examination is taken. This favours the projection method whose resolution is also the best. The overall times for contact, times-two and projection methods are very much the same with a given camera length.

Improved metallographic technique for revealing temper brittleness network in ordnance steels J. P. Rucker (*NPG Report No.* 1555; *PB* 131941, 1957, Aug. 28, pp.24) A proprietary wetting agent (cetyltrimethylammonium chloride) in an etching solution with or without nital gave improved results.

The processes of carbide formation during tempering of chromium steels B. A. Apaev (*Fiz. Met.*, 1958, **6**, (5), 858–865) Seven types of chromium steels were examined; quenched from between 1000°–1500° in a 10% solution of NaOH with subsequent cooling in liquid oxygen. The Cr/C ratio varied between 0·65 and 16·6. Some of the specimens were homogenized *in vacuo* at 1200° for 12 h before quenching. The experiments investigated the solution of Cr in cementite and the formation of special carbides. It was found impossible to describe the processes occurring in tempering by a definition generally applicable for all compositions, since, depending on the Cr concentration, not only does the rate of C and Cr redistribution vary, but a displacement occurs of the starting temperature for the solution of Cr in cementite and the conditions of iron carbide formation also change.

Structural stability and properties of heat-resistant chromium steels A. V. Merlina and A. M. Borzdyka (*Stal'*, 1959, (2), 160–165) The structural stability in prolonged use depends on the thermal stability of the carbide phase and to the strengthening effect of the solid solution, so that heat-stable finely divided V carbide in equilibrium especially in presence of Nb carbide increases stability and improves properties. The relative inferiority of 5%Cr steels is due to the carbide of M_7C_3 type, the 12%Cr steels contain $M_{23}C_6$ which is much more stable. Steel Kh12 MVBF with the Nb completely in the carbide phase had the highest structural stability.

Electron-microscopical structure of sheet steel containing various amounts of copper H. Tanimura and T. Yoshii (*Toyo Kohan*, 1953, June, 1–5) Grain boundaries were studied in 0·015%C steel containing 0·166–0·948%Cu in various heat-treated conditions. In the as-rolled state, precipitates of width 0·08–0·33μ were observed. Generally the precipitates increase with copper content, and markedly in specimens annealed at 500° and 600°C with copper contents above 0·349%. In the quenched state the precipitates disappear and boundaries are narrower than in the as-rolled state.—K.E.J.

Study of metallic carbides by electron diffraction. III. Iron carbides S. Nagakura (*J. Phys. Soc. Japan*, 1959, **14**, Feb., 186–195) [In English] These evaporated films were carburized in CO and ϵ, χ and θ carbides were formed below 250°C, at 250–350°C and above 350°C respectively. Irreversible transitions occur from ϵ to χ at 380–400°C and from χ to θ at ~550°C. Crystal growth studies suggest that the mechanism of formation of ϵ-carbide is different from that of χ and θ.

The electronographic determination of the structure of iron carbide Fe_3C E. G. Pinsker and S. V. Kaverin (**Kristallografiya*, 1956, **1**, (1), 66–72) A new iron carbide was observed when oriented films of α-Fe were carburized in CO or C_3H_2. It is most probably based on a slightly distorted α-Fe lattice with one molecule in the unit cell. The Patterson projection is given as well as the diffraction photographs.

Structural changes in 25 KhM-L steel with long exposures to heat S. S. D'yachenko, L. S. Palatnik, R. S. Kaplan, S. I. German, and N. I. Butko (*Fiz. Met.*, 1958, **6**, (6), 1122–1129) X-ray, metallographic and electron-diffraction investigations of the structure of this steel in long exposures to heat and in stressed and unstressed conditions have shown that after normalizing and tempering between 650° and 680° for 3 h, three carbides were observed in the precipitates $Cr_{23}C_6$; Mo_2C; Fe_3Mo_3C. With prolonged exposure between 500° and 550° agglomeration of the carbides occurs with the result that ferrite, without carbides, is formed along the pearlite grain boundaries. The agglomeration results in an increase of $Cr_{23}C_6$-type carbide.

The metallography of low-alloy creep-resistant steels E. Smith (*Cambridge Abstracts of Dissertations*, 1956–1957, (1959), 184–185) Steels containing Cr, Mo and V tempered from the martensitic condition show secondary hardening. A new replica technique using evaporated C is used for the electron microscope study of the process. It is shown to depend upon V carbide precipitation. Below peak hardness Fe_3C is present, at peak hardness a very fine structure is present which was resolved as thin plates. On further tempering VC appears and grows. Correlations of carbides in Cr and V steels with creep rate were obtained.

Dendritic silicon segregation in steels Ya. N. Malinochka (*Stal'*, 1958, (12), 1130–1132) A method of investigating microstructure in partially austenitized and quenched steel is described, revealing intercrystalline segregation and primary structure in cast Si steel.

Investigating the influence of dissolved carbon on recrystallization and long-term strength of the iron-nickel-manganese solid solution E. Z. Kaminskii and V. M. Rosenberg (*Fiz. Met.*, 1958, **6**, (6), 1036–1039) Introduction of carbon into this solid solution lowers the initial temperature of recrystallization. Dissolved carbon causes an increase in the resistance to failure at relatively high rates of deformation, and it causes a decrease in the resistance at relatively low rates. This influence of carbon is related to the strength of the interatomic bonds and to the increase in the distortion of the lattice.

The microstructure and mechanical properties of low and medium carbon steels F. A. Calvo (*Cambridge Abstracts of Dissertations*, 1956–1957, (1959), 182–183) These steels were examined after a variety of heat treatments at room and liquid N_2 temp. A low-temp. Vickers hardness apparatus was developed and correlations at the two temperatures were observed. Optical and electron microscope observations were made and ferrite grain and carbide particle sizes were determined and the former was related to yield stress and u.t.s. at −196°C. The proportionality of hardnesses at −184°C and +420°C is discussed in terms of mechanism of deformation.

Effect of nitrogen on austenite grain growth in medium-carbon steel with increased phosphorus content V. N. Svechnikov and I. Kh. Trush (*Metallov. Obra. Met.*, 1958, (9), 15–19) Steel with 0·44%C, 0·58%Mn, 0·33%Si, 0·018%S and 0·035%P was blown with pure N_2 in a high-frequency furnace while Fe-P was added bringing the N_2 content up to 0·037%. Some were deoxidized with Al. All were normalized at 900°C for 30 min and held at 800–1050°C at 50°C intervals for 90 min. Grain size was then estimated. N_2 prevents grain growth even in the absence of Al and counteracts the coarsening effect of P.

Heterogeneity in transformer-steel ingots N. F. Dubrov, I. A. Gorlach, N. V. Keis, and D. G. Zhukov, (*Stal'*, 1959, (2), 117–122) A study of the non-metallic inclusions in 6·2 t ingots is reported. Segregation of C, S, P, Al and N is demonstrated, especially of C and S. Heterogeneity is much reduced by keeping down to 0·02%C, 0·003%S and traces of Al. Electromagnetic agitation of electric furnace baths is advocated. The effects of Mn, Cr, P, N, Cu and low S contents (< 0·004%) should be further investigated.

Effect of orientation on strain-induced grain boundary migration in silicon-iron bicrystals K. T. Aust, E. F. Koch, and C. G. Dunn (*Trans. Met. Soc. AIME*, 1959, **215**, Feb., 90–96) Direction of boundary migration induced in Si–Fe bicrystals by a 7% cold-rolling strain and annealed at 1100°C was found to depend on orientation; results are given for several orientations related by a common [110] axis. Relative strain energies were obtained for the various orientations investigated (16 refs.)

Investigations of the domain structure in haematite by means of the electron beam method M. Blackman, G. Haigh, and N. D. Liagarten (*Proc. Roy. Soc.*, 1959, **251**, May 12, 117–126)

H-12 hot-work tool steel R. F. Harvey (*Prec. Met. Mold.*, 1959, **17**, Jan., 48, 70) A series of photomicrographs shows desirable and undesirable structures in the annealed and heat-treated condition for the 5%Cr H-12 tool steel.

Studies of alloy white cast iron. I. The effect of cooling rate of castings on the cast structures and Ar^1 transformation rates due to heat-treatment I. Fukumoto (*Nippon Kinzoku*, 1958, **22**, Apr., 199–203) Fundamental studies were made on irons containing Ni and Cr. When the Ni or Cr content is high enough, or when the specimen is cast in an iron or sand mould, pro-eutectoid cementite is not completely pptd. The concentration of the two elements in the austenite grains depends on the freezing rate.—K.E.J.

Graphitization of the Fe–C alloy surface in thermal treatment in vacuum I. I. Pyasetskii (*Dopovidi akad. Nauk Ukr. RSR*, 1958, (2),

139–143; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 506) Graphite formation in a wide range of irons is much more rapid at the surface than in the bulk of the metal. Microscopic defects are regarded as assisting nucleation.

The kinetics of first-stage graphitization in Fe–C and Fe–Co–C alloys A. S. Appleton (*JISI*, 1960, **194,** Feb., 160–168) [This issue].

Equilibrium diagram for phase volume in ShKh15 steel A. P. Gulyaev and B. M. Zel'bet (*Fiz. Met.*, 1958, **6,** (5), 843–848) The diagram shows the ratio between the specific volumes of austenite and martensite at different temperatures and with different carbon contents in solid solution. It may be seen from the diagram that the beginning of martensite formation corresponds to a definite specific volume of austenite related to the different carbon contents; it may also be seen that the curves characterizing the specific volumes of austenite and martensite at the beginning of the martensite transformation are parallel and equivalent and therefore express a constant difference in the interatomic distances along direction [101] in austenite and [111] in martensite lattices.

Correlated review of information relating to the mechanism of allotropic transformations in metals J. W. Spretnak (*AD* 84492; *AF WADC TR* 55–105; *PB* 134642, 1955, Mar., pp.95) Mechanisms of nucleation and growth and nucleation and shear are cited in ferrous and other systems and criteria for distinguishing between these mechanisms are given.

Cooling transformations in selected deep-hardening steels E. P. Klier and V. Weiss (*MET* 385–576 *F*1; *PB* 135631, 1957, June, pp.67) Dilatometric studies are reported. Cooling transformation diagrams and end-quench bar hardenability data are given, especially for 4340 steel austenitized by a two-step treatment. Structures are discussed with reference to their kinetics of formation.

A study of reversion phenomena in the carbon–alpha-iron system D. Keefer and C. Wert (*Trans. Met. Soc. AIME*, 1959, **215,** Feb., 114–119) It is shown that sudden increases in ageing temperature lead to reversion phenomena in C in the α-iron system. Of the variables, grain size, initial C in solution, and difference between initial and final ageing temperatures, initial carbon concentration has the greatest effect on reversion.

Investigation of phase transformation in some iron alloys S. A. Eliseev and B. G. Livshits (*Fiz. Met.*, 1958, **6,** (4), 657–661) Alloys which change their structure during a change from a high to a low temperature (K-state) have been investigated. These structural changes can best be judged from the change in the physical properties of the alloys. The specimens were sealed in quartz capsules to avoid oxidation, quenched in water from 1150°C and then tempered between 350–650° for 4 h. Specific electric resistance, magnetic saturation, hardness and thermal expansion were measured. Increase in resistance and hardness may serve as indications for the formation of the K-state. It is suggested that this formation is conditioned by the same causes as the so-called 'rising diffusion'.

Fundamentals of the transition temperature phenomenon in steel (*Quart. Progress Rep.* no.15, *Apr–June* 1955; *PB* 127111, 1955, Sept., pp.15) An all-glass vacuum melting unit to take larger melts was constructed and 1020 steel with grain size ASTM 6 was tested. Solid state outgassing lowered the transition temp. by 10°.

Influence of boron on the rate of the A_3 transformation of pure iron M. E. Nicholson (*AD* 67337; *AF WADC TR* 55–41; *PB* 134654, 1955, Feb., pp.9) Comparisons of Fe, Fe–B and Fe–Ni alloys were made.

Constitution and crystal structure of commercial iron–aluminium–carbon alloy in the alpha-solid solution range M. Vyklický and H. Tuma (*Hutn. Listy*, 1959, **14,** (2), 118–127) [In Czech] The ε phase field of the Fe–Al–C system was determined. The phase diagram of the commercial Fe–Al–C alloys in the region of 15–30% Al was derived from differential thermal analysis and metallographic studies. Only the solid-solution phase α was found, but in the presence of carbon also ε, graphite and Al_4C_3. A large number of partial phase diagrams and of micrographs are presented (20 refs).—T.G.

Influence of heat treatment on structure and cold-shortness of phosphorus steel V. N. Svechnikov and Yu. E. Yakovchuk (*Fiz. Met.*, 1958, **6,** (5), 849–857) Forty alloys were investigated; carbon content varying between 0·04 and 1·0% divided into five series according to phosphorus content; 0·05; 0·10; 0·15; 0·20; and 0·30%. Also alloys with high carbon and phosphorus contents and hypoeutectic alloys (up to 0·78%C). The differential dilatometric method was used. Heating and cooling rate was 3°/min. It was shown that between 728–722° the eutectoid chemical composition near to that of the binary system Fe–C showed little change with a changing P content. The beginning of the transformation, between 800–870°, at a constant temperature, is related to the redistribution of P between ferrite and austenite with an equilibrium state in which the ferrite is saturated with phosphorus.

The kinetics of the occurrence of deformation martensite V. N. Arskii and A. P. Gulyaev (*Fiz. Met.*, 1958, **6,** (5), 866–873) The specimens were high-nickel steels with a martensite point near room temperature. It was shown from experiments that martensite transformation with an externally applied load may be represented by curves. The effect of a reduction of temperature on the martensite transformation is similar in effect to an increase in the externally applied stress. It has also been shown that the rate of loading, and a constant load have the same influence on martensite transformation during cooling, as have the rate of cooling and isothermal treatments.

The structure of pearlite formed by the continuous decomposition of austenite I. Hrivňák *Hutn. Listy*, 1959, **14,** (2), 133–138) [In Czech] A great number of very good electron micrographs are presented to show that the tertiary cementite is a continuation of the pearlitic cementite and that the pearlitic ferrite could be a continuation of the proeutectoid ferrite. Inhomogeneities in the structure of cementite lamellae are revealed (20 refs).—T.G.

On the nucleation of pearlite M. E. Nicholson (*AD* 30040; *AF WADC TR* 53-316; *PB* 133512, 1953, Dec., pp.9) The currently accepted model does not accord with the change observed and a two-mode model is proposed where either ferrite or cementite may initiate pearlite nucleation. The rates agree with this model.

Kinetics of diffusion and phase changes in solid metals L. G. Stibe (*Cambridge Abstracts of Dissertations*, 1956–1957, (1959), 186–187) A mathematical study on the bases of Fick's law. The spheroidization of cementite plates in pearlite is briefly treated and the value of the approximate methods developed is shown. Some studies of nucleation are also included.

Tempered alloy martensites P. Payson (*Trans. ASM*, 1959, **51,** 60–93) The red hardness of alloy steels is reviewed and the effects on it of composition and structures, illustrated with electron micrographs is discussed. The identification of carbides by electron diffraction and the study of separated carbides are then outlined. Secondary hardening in alloy martensites is attributed to carbide precipitation and red hardness to the period of induction in the precipitation process. With Cr alone there is no secondary hardening as the precipitation of Cr_7C_3 does not cause any. Eight problems yet unsolved are stated (35 refs).

The influence of deformation on the parameter of the crystal lattice of austenite in Kh18N9T steel A. P. Gulyaev and Ya. E. Saichuk (*Fiz. Met.*, **6,** (5), 947) One mm dia. specimens of this steel were subjected to two different heat treatments: quenching alone and followed by stabilization. The first treatment promotes full transition of carbides into solution and after quenching ensures a supersaturated solution; the second treatment has the opposite effect, i.e. the elimination of carbides from solution during stabilization. The specimens were subjected to tensile stresses. X-radiographs were taken by the Leba method and were then measured by a Zeiss apparatus and the parameters of the crystal lattice plotted against deformation.

Influence of previous heat treatment on the kinetics of pearlite-troostite decay of supercooled austenite V. G. Gorbach and V. D. Sadovskii (*Fiz. Met.*, 1958, **6,** (4), 665–672) Austenite structure may vary for the same temperature, depending on previous treatment and the rate of the second heating. The character of the differences is such that they influence the regions where the growth nuclei of the transformation appear, and also the diffusion coefficient. They affect, therefore, the kinetics of the break-up of the austenite. Structure differences observed in the non-diffusion formation of austenite result in the speeding up of the pearlite-troostite transformation as compared with the austenite transformation for the same grain size.

Study on the graphitisation of high carbon steel. I. Factors controlling the graphitisation at sub-critical temperature of high carbon steel. 2. N. Yamanaka and K. Kusaka (*Tetsu to Hagane*, 1959, **45,** Jan., 45–51) Cold deformation accelerates graphitization, and compressive forces are as effective as tensile. Heating to 870°C and furnace cooling after cold drawing markedly inhibit graphitization on subsequent heating at 650°C. H_2 (as opposed to N_2 or vacuum), used as an annealing atmosphere at 650°C, had a stabilizing effect on carbide and inhibited graphite formation. Cast-iron chips used as packing material cause less graphitization than a N_2 atmosphere or vacuum. **II. Effect of aluminium and nitrogen on the graphitisation of high-carbon steel. I** (Feb., 110–117) Results are given from steels including those made from electrolytic iron under varying conditions of heat treatment. Acid-soluble Al had a promoting effect on graphitization. N_2 in solution (calculated) inhibited the breakdown of cementite to graphite after water-quenching from 870°C.

On the effect of arsenic additions on the structure, graphitization and properties of grey cast iron I. Pavlik (*Slévárenství*, 1959, **7,** (4), 159–166) As does not change the amount of graphite precipitated, but affects its form. In the presence of 0·27%As or more, with P simultaneously present, a new component, probably an Fe–P–As phase, is formed by interaction of the As with cementite. The As itself is insoluble in the cementite but soluble in the ferrite. With up to 0·1%As the mechanical properties of the cast iron are improved, with higher contents worsened. Corrosion resistance and fluidity are also improved by small additions of As.—P.F.

The effect of aluminium on sigma formation in iron-chromium system M. Tagaya, S. Nenno, and M. Kawamoto (*Nippon Kinzoku*, 1958, **22,** Aug., 387–389) Fe–Cr–Al alloys containing 20–35%Cr and 0–4%Al were aged for 720 h at various temp. Sigma was not formed with <25%Cr; with 30%Cr, 0·3%Al accelerated sigma formation, but more retarded it. Alloys containing 35%Cr showed much sigma, but >1·26%Al suppressed it. The rate of sigma formation was a max. of 700°C.—K.E.J.

The constitution of Fe–Cr–Mn alloys B. Potůček (*Hutn. Listy*, 1958, **13,** (12), 1070–1076) Recent work on the structure of these alloys is critically surveyed. It is shown that there are significant differences between the extents of the domains of corresponding structures in the Fe–Cr–Mn and Fe–Cr–Ni systems, particularly in relation to the σ-phase (44 refs).

Structure of the steel containing 8% Cr, 3% Mo and 1% Ti J. Ullmann (*Sborník (Ostrava)*, 1958, **4,** (6), 547–559) Precipitation processes occurring on tempering this steel, designed for use up to 620°C, were studied. The most important hardening process involves the precipitation of a carbide of type $M_{23}C_6$. The precipitation hardening is also accompanied by the formation of a metastable carbide. The intermetallic compound Fe_2Ti is formed in addition, and may have an unfavourable influence on the precipitation hardening.

Crystallographic relationships between austenite and σ-phase formed by cold-working in the unstable stainless steels P. Bastien and R. Margerand (*Compt. Rend.*, 1959, **248,** April 27, 2480–2482) Compression of low-C 18–8 steel produces σ-phase which is oriented with regard to the austenite in accordance with Bain's theory. A mechanism for the γ–σ

change is advanced in terms of dislocation theory.

Studies of the conditions for the liberation of cementite from iron-carbon alloys R. B. Golubtsova (*Doklady AN*, 1959, **124,** (1), 91–93) The method of electrochemical, anodic solution was applied for the extraction of cementite from alloys of composition C5%, Fe95%, and C2%, Fe98%. The alloy samples were used as anodes and the electrolyte consisted of a mixture of hydrochloric and citric acids without any KCl. The optimum current density was 0·03–0·05 a/cm² and the product, as tested microchemically and by X-rays, was a pure Fe_3C.—S.I.T.

On the use of differential thermal analysis for the determination of equilibrium diagrams H. Tůma and M. Vyklický (*Hutn. Listy*, 1958, **13,** (12), 1077–1081) A simple apparatus for DTA developed by the authors is described. The equipment is suitable for use with very small quantities of the alloys, and can be used up to about 1500°C.—P.F.

Investigation of the Ti-rich Ti–Fe–Mn system. I. On the $TiMn_2$–Mn range of the binary Ti–Mn system Y. Murakami and T. Enjyo (*Nippon Kinzoku*, 1958, **22,** May, 261–265) M.p., microscopy, microhardness, and X-ray methods are used. A binary eutectic reaction liquid $\rightleftharpoons TiMn_2$ + Mn is found and the invariant point is supposed to be at 83·5wt% Mn at ~1185°C. The solid solubility range of $TiMn_2$ enlarges from 63·7 to 70·9wt% at 1150° and narrows with decreasing temp. Lattice parameters decrease with Mn content. The maximum solubility of Ti in Mn is ~10wt%Ti at eutectic temp. and the solubility range appears to narrow slightly with decreasing temp. **II. On the liquidus surface of the Ti–Fe–Mn system** Y. Murakami, Y. Yukawa and T. Enjyo (265–269) A liquidus surface diagram derived from n.p., hardness, and microscopical observations is presented. The $Ti(Fe, Mn)_2$ is a continuous solid soln. in a wide range between $TiFe_2$ in the Ti–Fe binary system and $TiMn_2$ in the Ti–Mn binary system; the ternary system has two invariant reactions.—K.E.J.

The effects of calcium on the decomposition rate of carbide in Fe–C–Si alloys M. Maruyama and M. Ito (*Imono*, 1959, **31,** March, 172–178) [In Japanese] Decomposition rates were measured at 600, 700, and 800°C. Calcium (CaSi) additions lowered the stability of carbides, in decreasing order of primary, pearlitic, and ledeburitic cementite. The decomposition rate was highest at a slightly higher C content than the C-saturated solubility of austenite. Similar results were obtained with steel at temp. between 700°C and A_1.—K.E.J.

Equilibrium diagram of the system Fe–C–Si I. Iitaka (*Imono*, 1959, **31,** March, 165–171) [In Japanese] A stable equilibrium diagram is drawn, based on the author's Fe–C diagram; it differs from the one given by Jass. Vertical sections of the space model at Si contents of 1·0, 2·0, 2·6, 6·0, 7·0, 9·0, and 12·0%, and horizontal sections at 700, 800, and 1100°C are given.—K.E.J.

Thermodynamics and kinetics of martensitic transformations L. Kaufman and M. Cohen (*Progress in Metal Physics*, 1958, **7,** 165–246) A review of the transformation in the most general sense of a diffusionless transformation to which hardness, lattice structure, athermal kinetics and insuppressibility are inessential. Theories and models are considered and the free energy and nucleation and shear aspects are fully discussed (98 refs).

Studying the texture of bands of different thickness of the 50% Fe–50% Ni alloy M. M. Borodkina and N. P. Gromov (*Fiz. Met.*, 1958, **6,** (5), 819–824) The most intensive orientation in the deformed bands in samples of this 50NP alloy of different thicknesses are the orientations (110), [112], (112), [111], (236) and [533]. On annealing the 0·05 mm thick band, a sharp cubic recrystallization structure is formed (001), [100]. The difference between the deformation structure of the 0·005 and 0·05 mm thick bands consists in a weakening of (110), [112] orientation and an increase in the portion of disoriented crystals in the thinner band. A decrease in thickness from 0·05 to 0·005 mm results in the gradual fading of the recrystallization structure.

Influence of carbon on the stabilization of austenite in Fe–Cr–Ni alloys N. A. Borodina, K. A. Malyshev and V. A. Mirmel'shtein (*Fiz. Met.*, 1958, **6,** (5), 937–938) Experimental results show that for austenite stabilization by isothermal exposure above the martensite point, carbon (or nitrogen) must be present in steel. To stabilize austenite as a result of direct or reverse martensite transformation, the presence of carbon (or nitrogen) is not essential.

Investigation of martensite transformation in powder austenite A. P. Gulyaev and V. D. Zelenova (*Fiz. Met.*, 1958, **6,** (5), 945–946) Experiments have shown that the martensite transformation in the powder austenite monocrystal does not take place, whilst in compacted steel of the same composition it does occur. Stresses of the 2nd order are obviously necessary for the martensite transformation which takes place by contact between differently oriented austenite crystals.

Formation of σ-phases in the systems rhenium-manganese and rhenium-iron Ch. V. Kopetzkii, V. Sh. Shekhtman, N. V. Ageev, and E. M. Savitzkii (*Doklady AN*, 1959, **125,** (1), 87–88) An alloy of Fe–Re contained 26·45%Fe, after annealing at 1500°C for 6 h, subjected to X-ray study gave lines characteristic of σ-phase and the calculated parameters are $a = 9·02$ C = 4·69Å. An alloy of Mn–Re contained 21·23%Mn, after annealing at 1000°C for 360 h, also gave X-ray spectrum lines characteristic of σ-phase, and $a = 9·14$, $c = 4·75$ Å.—S.I.T.

A search for the sigma-phase in the Fe–W and Co–W alloy systems E. C. Van Reuth (*Trans. Met. Soc. AIME*, 1959, **215,** Apr., 216–218) No sigma could be found in a study of 53 alloys. ξ-phase was confirmed in the Fe–W and found in the Co–W systems. The peritectic temperature of 1640°C in the Fe–W systems appears doubtful.

The system zirconium–iron–tin. Status Report No.4 July 1957–Mar. 1958 L. E. Tanner (*AECU* 3692, 1958, Apr., pp.16) (From *US Govt. Res. Rep.*, Nov.14, 1958, **30,** (5), 469. No abstract).

Liquidus–solidus relations in the system iron–aluminium J. R. Lee (*JISI*, 1960, **194,** Feb., 222–224) [This issue].

The constitution of the iron–niobium–silicon system H. J. Goldschmidt (*JISI*, 1960, **194,** Feb., 169–180) [This issue].

Formation of beta-manganese-type structure in iron-aluminium-manganese alloys D. J. Schmatz (*Trans. Met. Soc. AIME*, 1959, **215,** Feb., 112–114) Fe–Al–Mn alloys containing 5–20% Al and 5–67%Mn were produced and examined metallographically. The effects of quenching temperature on structure were investigated.

Iron-manganese, iron-molybdenum, iron-nitrogen (*Structure reports*, 1951, **15,** (1957), 83–85) The lattice structure of nitrogen martensite is given. **Iron-oxygen-titanium, iron-phosphorus, iron-silicon** (85) Notes only. **Iron-titanium** (86–87) The equilibrium diagram is shown and the structure of FeTi is briefly indicated. **Iron-zirconium** (87–88) The equilibrium diagram is given.

X-ray investigation of structures in Fe–Mo and Fe–Mo–Co ferromagnetic alloys B. Ya. Pines and I. N. Barutkin (*Fiz. Met.*, 1958, **6,** (5), 832–837) The change in the coercive force of these alloys during heat treatment is accompanied by a change in the 'form' of the interference lines. The faded X-ray lines corresponding to the solid solutions of these alloys are conditioned by the micro-deformation of the crystal lattice. The causes of the high coercive forces in the Fe–Mo alloys are the considerable microstresses, (up to 80 kg/mm²) occurring in the solid ferromagnetic solutions with the formation of the Fe_3Mo_2 phase during tempering. In the Fe–Mo–Co alloys the coercive force is caused by microstresses in the solid ferromagnetic solutions and also by the finely dispersive inclusions in the θ-phase.

CORROSION

The corrosion of mild steel in flowing gases containing sulphur T. K. Ross and A. J. Macnab (*Werks. Korr.*, 1959, **10,** July, 417–422) In the production of lampblack from oil-refinery residues corrosion of the mild steel plant occurs where the steel comes into contact with the combustion gases which contain SO_2 and SO_3. This type of corrosion was studied in special experiments. In the absence of air in the combustion gases considerable amounts of H_2 and CO are present so that sulphide scale is formed at the steel which spalls off if the steel is under mechanical stress thus exposing fresh surfaces to further attack producing heavy corrosion.—T.G.

Tube pitting on melting furnace firing systems K. Pawlik (*VDIZ*, 1959, **101,** April 11, 418–419) The pitting of tubes in such systems is due partly to corrosion and partly to erosion, and can be obviated by improved firing technique and by obtaining a suitable slag viscosity.

Corrosion of steel in apparatus of coke-chemical plants E. V. Zotova (*Koks i Khimiya*, 1958, (8), 49–51; *PB* 141309T; from *Techn. Translations*, 1959, **1,** April 3, 233) Tests in H_2SO_4 were made. The rate depended mainly on the type of steel used. The highest resistance was shown by Ni–Cr–Mo–Cu steel and Ni–Si steel. Tests were carried out in saturators, washers, fractionating columns, tar stills, and pitch columns.

An investigation into the structure and properties of high-pressure steam tubes after prolonged operation in power plants E. S. Ginzburg (*from *The Strength of Metals*, Ed.—N. V. Ageev, Moscow 1956, 58–66) Results are given of investigations of the microstructure, mechanical properties, creep resistance and long-time strength of four high-pressure steam power plant tubes after operating at 490°C for 38,000–53,000 h at high pressure.

Mechanism of stress-corrosion cracking (*NBS Techn. Bull.*, 1959, **43,** Mar., 63–64) Studies on Mg alloys are described, but the findings are apparently applicable to ferrous metals.

Metallurgy important factor in corrosion science A. I. Petrovich (*Ind. Eng. Chem.*, 1959, **51,** Feb., 73A–74A) Dislocation theory and the role of H_2 are considered.

Special features of anodic activation of chromium and chromium steels. II. Influence of the acidity of the solution E. I. Antonovskaya and A. M. Sukhotin (*Zhur. Fiz. Khim.*, 1958, **32,** (8), 1842–1846) It was shown previously that, in solution, 1Kh13 and 1Kh25 Cr steels at a high anode potential, deposit a different proportion of Cr and Fe than exists in the steel and that, as deposition proceeds, a solid solution of Cr and Fe in the steel is formed which is continuously depleted in Cr. Under such conditions the protective role in the steel is carried by the iron, the passivity of which depends on its amount in the alloy and on the effect of substances in solution influencing this passivity. The anode activation of Cr in acid solutions may be expressed by the reaction $Cr_2O_3 + 4H_2O > Cr_2O^{2-}_7 + 8H^+ + 6e$ corresponding to the standard potential of 1·27 V which is near to the activation potential. This potential decreases linearly with an increase in pH values. The anodic activation potential of Cr steels, however, is independent of the pH values and a mechanism has been proposed for this anodic oxidation which does not include water molecules or hydrogen ions thus: $Cr_2O_3 + Fe_3O_4 \rightarrow Cr_2O^{2-}_7 + 3Fe^{3+} + 7e$ ($\phi_0 = 1·14$V).

Sixth report of the corrosion committee (*ISI Special Report* No.66, 1959, pp.217) Work on atmospheric corrosion, corrosion by industrial waters, marine corrosion, soil corrosion, protective coatings (Al, Zn, Cd), test procedures and fundamental research is summarized. Series of atmospheric corrosion tests, some dating from 1930, are reported and the results are discussed. Panels are illustrated and correlations with climatic conditions are noted. Numerous paint trials are included and the whole is summarized. Corrosion and protection studies up to 300°C in various locations are considered and marine corrosion service tests are reported. A list of publications and tables of data are added.

Atmospheric corrosion of metals. Part II. Corrosion of metals in Bombay B. Sanyal,

A. N. Nandi, A. Natarajan, and D. Bhadwar (*J. Sci. Ind. Res.*, 1959, **18A,** Mar., 127–131) Mild steel and other metals were exposed outdoors and indoors and rate of corrosion was correlated with humidity. Indoor corrosion of steel was one-third that of outdoor corrosion.

Well completion and corrosion control of high-pressure gas wells (*Corrosion*, 1959, **15,** Feb., 73–75) A status report of NACE task group T–1B–1 on high-pressure well completion and corrosion mitigation procedure. A fact-finding report on 166 high-pressure wells with particular emphasis on failures of tubing.

Mechanical properties and corrosion-resistance of oil-well tubing F. A. Prange (*Corrosion*, 1959, **15,** Feb., 49–54) The author discusses the application of the various grades of tubing in sweet and sour condensate wells and sweet and sour oil wells. Sour condensate wells are particularly troublesome since the sulphide stress cracking is closely related to the mechanical properties. Stress corrosion may be a serious problem in the high-strength steels. Common defects found in the various grades of steel are discussed.—T.G.

Corrosivity of soil N. D. Tomashov and Y. N. Mikhailovsky (*Corrosion*, 1959, **15,** Jan., 77–82) Theoretical foundations of a suggested method for the appraisal of the corrosiveness of soils are discussed in detail. An apparatus is described for the measurement of corrosion characteristics of soil under field conditions. Data are presented to show the correlation between instrument readings and corrosion rates in various types of soil.—T.G.

Stress corrosion of austenitic stainless steel by high-temperature solutions and contaminated steam P. P. Snowden (*JISI*, 1960, **194,** Feb., 181–189) [This issue].

Chloride stress-corrosion cracking of the austenitic stainless steels J. P. Engle, G. L. Floyd, and R. B. Rosene (*Corrosion*, 1959, **15,** Feb., 69–72) A contribution on the work of NACE task group T–8A on chemical cleaning. The austenitic (AISI 300 series) stainless steels are highly susceptible to chloride stress-corrosion cracking. A study was undertaken to define conditions under which HCl can be safely used for cleaning equipment containing these steels. Indications are that cracking occurs in neutral chloride solutions when passivity is destroyed at localized areas of film breakdown. If the entire surface is activated, as in the presence of HCl, no cracking will result.—T.G.

The corrosion of tin plate M. Hanada (*Toyo Kohan*, 1954, **3,** May, 49–59) A review, covering the effects of steel composition and the tinning process on corrosion, the nature of pores in the plating, and the effects of shipping, storage and contents on the tinplate (31 refs).

Salt water corrosion and corrosion fatigue properties of Allegheny Ludlum AM 350 alloy W. L. Williams (*NS* 014–123; *NAV EES* 040034*J*; *PB* 133248, 1956, May, pp.11) The alloy is a Cr–Ni–Me stainless steel austenitic at room temp. and hardenable by transformation to martensite at −100°F. Its corrosion properties were tested and resistance was good but local crevice corrosion appeared. Its corrosion fatigue resistance equalled that of the best of the other high-strength corrosion-resistant alloys.

Results of the examination of carbon steel pipe and small heat exchanger removed from NRTF R. S. Gilbert (*WAPD–A1W (PCh)*–61, 1956(?), pp.10; from *US Govt. Res. Rep.*, 1958, **30,** Nov. 14, 473 No abstract).

Recent research on boiler tube corrosion E. C. Potter (*Chem. Ind.*, 1959, Mar.7, 308–314) A statistical study of power-station observations is given and compared with dissolved O_2 data. Mechanisms are then considered and boiler trials are considered. Continental experience with thinner tubes is referred to.

ASTM obtains the facts on corrosion of castings J. H. Lansing (*Foundry*, 1959, **87,** Feb., 118–121) The work of the ASTM on the study of the corrosion of castings is briefly described and the importance of exposure sites stressed. Tests procedures often extending over many years are outlined.—T.G.

Studies on the corrosion behaviour of non-drying oils and fats with special reference to modern lubricants and metal protective agents A. Bukowiecki (*Schweiz. Arch. Wiss. Tech.*, 1959, **25,** Apr., 126–143) A review and an account of exposure trials on iron specimens of a large range of oils and fats (245 refs).

Corrosion studies in refrigeration practice A. G. Arend (*Corros. Prev.*, 1959, **6,** Feb., 33–35) Corrosion of Fe and Cu in presence of brines and ammonia is briefly considered.

All Union Scientific/Technical Conference on corrosion and protection of metals. Moscow, May 19–24, 1958 Abstracts of papers (*Plating*, 1959, **46,** Mar., 262–266). **Electrodeposition of a durable alloy of nickel–phosphorus** M. E. Goldstein. **The cathodic processes on electrodeposition of the alloy iron–nickel** P. S. Titov and N. V. Korovin. **The influence of the structure of steel on the inclusion of hydrogen during electrolytic treatment** G. D. Volpert **Zinc plating steel springs and retention of their mechanical properties** A. M. Guisberg and A. P. Gorina **The influence of electrolytic zinc plating on the mechanical properties of steel** I. I. Maroz and N. T. Kudryavtsev. **Investigation of the tendency to cracking of high strength steel in the deposition process of galvanic coatings.** N. V. Garshina. **Increasing the corrosion resistance of electrolytic zinc coatings by surface treatment and the alloying of zinc with other metals** N. T. Kudryavtsev and K. M. Tyotina. **The technology of deposition of alloys of Sn–Zn and Sn–Cd and their corrosion resistance to conditions approximately like those in the tropics** P. M. Byacheslavov. **Choice of protective coatings for objects to be used under tropical conditions** F. F. Ashozin and Yu. A. Smirnova. **Comparative results of experiments on metallic materials and coatings in laboratory conditions and on corrosion in stations within the Chinese National Empire** V. V. Usov and E. M. Muravyeva. **The problem of the mechanism of the alkaline oxidation of steel** A. V. Shroeder and A. G. Arakelov. **The effective protection of steel against corrosion by different methods of oxidation** V. A. Titov and A. R. Yakubenko. **Automatic electronic apparatus for maintaining an assigned current density, time of coating, and temperature of electrolyte in galvanic baths** Yu. V. Gogish-Klushin. **Electronic apparatus for regulating the galvanic coatings process Purp-1** L. M. Mashevich and A. M. Ginberg. **Internal tension in bright galvanic deposits** Yu. V. Lizlov and A. G. Samartsev. **Development of a method of analysis of hydrofluoborate electrolyte** E. Lerman. **Electrochemical method to determine the adhesion of a metallic coat** A. I. Lipin Long abstracts are given and conclusions are in general set out.

Corrosion of 18–8 austenitic steel in nitric acid environments containing chlorides T. E. Evans and P. A. Hayes (*IGR–TN/C–*305, 1956, pp.20; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 500) Selective attack occurs in contact with condensate but not in bulk solution. Controlling factors are temp., free acid, Cl- and dissolved O_2. The findings are applied to the corrosion of cascade dissolvers.

Stress-corrosion failure of a high-pressure water–water cooler in the dynamic corrosion loop at Capenhurst G. E. Marchment (*IGR–TN/CA–*974, 1958, pp.14; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 500) Failure of a stainless steel cooler cooling water from 300 to 40°C in presence of dissolved chlorides is reported. An amended cooler design is suggested.

Corrosion of materials in lithium hydroxide solution at 600°F for 1500 hours R. W. Barret (*WAPD, SFR–Ch–*138, 1955, pp.27; from *Nuclear Sci. Abs.*, 1959, **13,** Jan. 31, 97) Corrosion of stainless steels was less than in water with 1–5 ppm. NH_3 at 500°F, being ~23 mg/dm.^{2} C steels and 1·25–2·25%Cr steels in general showed rapid initial attack and build up of scale for 250 h and relatively mild corrosion afterwards. Croloy CR–5 with 5% Cr had about half the corrosion rate of C steel.

Effect of molten boron oxide on selected high-temperature alloys D. Roller and C. R. Andrews (*Corrosion*, 1959, **15,** Feb., 85–96) A number of superalloys including stainless steel 310 containing 24%Cr were subjected to a series of cyclic exposures to molten boric oxide. The steel showed slight surface pitting and the formation of metallic compounds. These compounds were dark blue and formed mostly on the edges of the test specimen.

The physical and chemical changes in ferrous materials associated with liquid metal environment A. A. Smith (*Cambridge Abstracts of Dissertations*, 1956–1957, (1959), 183–184) Cast irons and steels were heated in a vacuum in contact with liquid Na and a few other low melting metals, weight and structural changes and particularly decarburization were observed. Graphite irons were particularly susceptible to decarburization. Surface etching occurred and high-C layers were formed on steels and cast irons due to carbide stabilization caused by a transfer from the reaction vessel to the metal surface.

Test of proposed design S2G bellows in sodium G. E. Kennedy and E. C. King (*NP–*7111, *Memo. Report* 120, 1956, pp.9; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 502) The bellows were of stainless steel. None failed even up to 90000 cycles.

Corrosion of stainless steel and titanium in Purex 2WW M. C. Fraser (*HW–*43986, 1958, Mar., pp.18; from *US Govt. Res. Rep.*, 1958, **30,** Nov. 14, 469; no abstract).

Institute of Fuel symposium on the work of the boiler availability committee G. Manasseh (*BCURA Monthly Bull.*, 1959, **23,** Mar., 97–103) Deposits and corrosion problems, sulphur trioxide determination and corrosion inhibition studies are reviewed.

The corrosion of metals in synthetic atmospheres containing sulphur dioxide B. Sanyal and D. V. Bhadwar (*J. Sci. Ind. Res.*, 1959, **18A,** Feb., 69–74) Mild steel and non-ferrous metals were tested in humid atmospheres. Each metal requires a critical minimum humidity for attack, 60 and 75% RH for steel. Rise in temperature increases corrosion until the lower solubility of SO_2 in condensates reverses the trend.

Comparative corrosion resistance of 200 and 300 series stainless steels in chemical manufacturing processes A. C. Hamstead and L. S. Van Delinder (*Corrosion*, 1959, **15,** Mar., 147t–157t) The corrosion resistance of several experimental and commercial chromium–nickel–manganese steels has been compared with that of the 18–8 chromium–nickel steels. In a wide range of chemical services the former could be used in place of the latter. In a few instances the annealed chromium–nickel–manganese types were better than the usual 18/8 chromium–nickel steels. In the sensitized condition however the commercial grades at least were more susceptible to intergranular attack.

The use of stainless steels in corrosion control J. P. Ogilvie (*Cam. Min. Met. Bull.*, 1959, **52,** Feb., 85–89) Classification of stainless steels and their resistance to acids and NaOH are discussed.

Corrosion and decarburization of the ferritic chromium–molybdenum steels in sodium coolant systems W. C. Hayes and O. C. Shepard (*NAA–SR–*2973, 1958, Dec. 1, pp.33; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 500) Exposure tests of ferritic and austenitic specimens at 1025°F in a high-velocity loop and at 1050°F in a low-velocity loop (with 500° temp. gradient) are reported. Corrosion was negligible but decarburization occurred in low-Cr steels, the reaction is diffusion-controlled. 5%Cr and Ti and 7 and 9%Cr steels were neutral in carbon activity. Steels with 1·25 and 2·25%Cr were decarburized in C-contaminated Na while with 5%Cr above they were carburized. The effect is correlated with C activity.

Carbon steel in high temperature water G. E. Moore (*CF–*57–1–26, 1957, Jan., pp.34; from *US Govt. Res. Rep.*, 1958, Dec. 12, 633, no abstract).

The growth and scaling characteristics of cast irons in air and steam G. N. J. Gilbert (*BCIRA J. Res. Dev.*, 1959, **7,** Feb., 478–566) Long term tests in air and steam are reported which indicate that cast iron is structurally stable and not subject to growth at temperatures up to 400°C.—A.G.

Scale and corrosion (*Engineer Foundryman*, 1959, **24,** Jan., 59–60) New compounds for the

prevention of scale and corrosion in steam installations are briefly described.—A.G.

The thermal oxidation properties of metallic coatings R. L. Samuel (*Prod. Fin.*, 1959, **12,** Feb., 73–86) A discussion with reference to the diffusion of Zn, Si, Al, and Cr and the use of facing alloys and cladding. Scaling conditions and diffusion coatings are reviewed and the coating of iron and steel, the assessment of oxidation properties and the oxidation-resistance of coated steels are described. Non-ferrous metals are then considered.

Oxidation of metals W. W. Smeltzer and L. H. Everett (*Ind. Eng. Chem.*, 1959, **51,** March, Part II, 406–411) A review of recent work with 196 refs. Mainly non-ferrous.

High temperature oxidation of chromium–nickel steels D. Caplan and M. Cohen (*Corrosion*, 1959, **15,** Mar., 141–146) Stainless steels of types 302, 309 and 330 were examined at 1600–2000°F. Breaks are shown corresponding to rapid oxidation when the protective scale layer breaks up, and accumulation of SiO_2 at the interface promotes the process, it is also supposed that voids have the same effect. Another type arising from the extreme protectiveness of an initial film markedly affected by surface preparation and pretreatment is distinguished.

On the passivity of iron in acid solutions. II. A. M. Sukhotin and K. M. Kartashova (*Zhur. Fiz. Khim.*, 1958, **32,** (7), 1632–1637) It was suggested previously (*ibid.*, 1957, 1256) that there exists an analogy between the behaviour of magnetic iron oxide with the passive iron electrode and the kinetic characteristics of cathodic reduction of magnetite and the substance of the passivating film. This has now been confirmed. The time–potential curves of an iron electrode in acid solution show a further level section. The analysis of the dependence of this section on the pH of the acid solution shows that this level section of the curve corresponds to the electrochemical reduction of the passivating film, whilst the first section of the curve is probably due to the reduction of Fe^{3+} (aq) to Fe^{2+} (aq) ions.

Rate of oxidation of steel and cast iron in a steam atmosphere P. Széki (*Acta Techn.*, 1958, **22,** (1–2), 129–134) The rate of scaling of mild steel and cast iron was determined in laboratory experiments in steam at 500 to 750°C. From the increase in weight of the specimens the rational constant of oxidation was calculated, together with the equations of the straight lines giving the relationship between the logs of the oxidation constants and the reciprocal value of the absolute temperature. The equation for steel is:

$$\log k = -\frac{8450}{T} - 0{\cdot}922$$

and that for cast iron:

$$\log k = -\frac{8500}{T} - 0{\cdot}626$$

On the changes in the stability zones of wustite in the Fe–O constitutional diagram at high pressures V. I. Arkharov and D. K. Bukychev (*Fiz. Met.*, 1958, **6,** (6), 1027–1030) The authors showed in *Doklady AN, SSSR*, 1957, **113,** 791, that at high pressures wustite decomposes between 500–450° and in (*Fiz. Met.*, 1958, **6,** 186) that wustite forms at high pressures within the same temperature change with the oxidation of iron. To explain this apparent contradiction the authors suggest that pressure shifts the boundaries of the wustite homogeneity zone on the constitutional Fe–O diagram towards greater oxygen content. With the oxidation of iron at high pressure wustite may form, but in a region correspondingly enriched with oxygen. The experiments described bear out this hypothesis.

Thin metal films as corrosion indicators R. B. Belser and F. E. Hankinson (*WADC-TR-57-662; AD-155516*, 1957, Nov., pp.97; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 503) Fe and 8 other metals were exposed on glass or plastic substrates as indicators for corrosion conditions, only Fe and Mn proved suitable. The part played by the adsorbed gas layer on glass is evaluated.

A constant temperature corrosion probe R. W. Kear (*J. Inst. Fuel, preprint*, 1959, pp.7) The device is for insertion in boiler flues and similar locations. Organic liquids are used as coolants boiling over the range 106–290°F.

Comparative corrosion resistance of 200 and 300 series stainless steels in chemical manufacturing processes A. C. Hamstead and L. S. Van Delinder (*Corrosion*, 1959, **15,** Mar., 147–157) Substitution of Ci–Ni–Mn for the higher Ni steels is shown to be possible in some cases. Cases where intergranular attack was greater with 201 and 202 samples were found.

Corrosion tests on metallized coatings AWS Committee on Metallizing (*Weld. J.*, 1959, **38,** Mar., 215–221) Long-term exposure tests on steel panels sprayed with Zn, Al and steel SAE 1010. An automatic machine was used for coating, spraying 36 panels at once. Vinyl-bound coatings and chlorinated rubber were applied as sealing coats to some of these. Atmospheric exposure and sea-water immersion tests are illustrated and evaluated.

General and intergranular corrosion of austenitic stainless steels in acids; effect of cations in the acids and the influence of heat treatment and grain size of the steel M. A. Streicher (*J. Electrochem. Soc.*, 1959, **106,** Mar., 161–180) Such cations as Cr^{+6}, Ce^{+4} and ferric ion increase attack in HNO_3. A 24 h evaluation test with H_2SO_4–$Fe(NO_3)_3$ may be possible. $CuSO_4$ has an effect similar to $Fe_2(SO_4)_3$ but weight loss is not so reliable as a measure of corrosion. Metallic copper greatly accelerates intergranular attack when in contact with the specimen. Dissolution is predominantly under anodic control.

Iso-corrosion rate curves for high temperature hydrogen hydrogen sulphide E. B. Backensto and J. W. Sjoberg (*Corrosion*, 1959, **15,** Mar., 125t–127t) Lines of constant corrosion rate, from 0·001 to 0·50 in. per year, are presented for 0–5% chromium steels and for chromium–nickel austenitic steels in hydrogen containing up to 10% by volume hydrogen sulphide over the temperature range 500 to 1400°F. The data were obtained at hydrogen pressures between 175 and 500 p.s.i.g.

Factors influencing the rate-of-pickling test on tinplate steel R. M. Hudson and G. L. Stragand (*Corrosion*, 1959, **15,** Mar., 135t–140t) Results are presented of a study of the influence of cleaning, annealing and other factors on pickle-lag time for tinplate steel. It is concluded that explanations of 'lag' in terms of oxidation or decarburization are not always tenable. The high concentrations of certain elements in the surface during annealing may be related to the phenomenon. Mechanisms have been studied and proposals are made for further lines of research.—J.F.S.

Corrosion resistance, especially the corrosion fatigue of nitrided titanium steels M. Tömöry (*Per. Polytechn.*, 1958, **2,** (4), 291–308) Corrosion fatigue experiments are described, in which nitrided Ti-bearing steels are compared with other plain carbon and alloy steels in their resistance to corrosion in various media. The use of nitrided Ti steels can be recommended where corrosions and repeated stresses or wear are encountered. In cases where corrosion fatigue is to be expected, Ti steels with a Ti/C ratio of <4 should be used; for conditions giving corrosion, associated with wear, cavitation or erosion, steels with a Ti/C ratio >4 should be used (13 refs).

Chemical and electrochemical aspects of the corrosion of nuclear reactors G. H. Cartledge (*Corros. Anticorros.*, 1958, **6,** Nov., 387–401) After a general discussion of kinematic aspects of corrosion, the author discusses in detail aspects of corrosion peculiar to conditions existing in nuclear reactors, under the headings of energy liberation, radiation, and nuclear fission (44 refs).

The influence of photosynthesis on the corrosion of steel in sea water A. Hache, L. Barriety, and J. Debyser (**Werks. Korr.*, 1959, **10,** March, 145–148) Field and laboratory tests with sea water and NaCl solutions have shown that a linear relationship exists between the content of dissolved oxygen due to photosynthesis by algae, and artificially added oxygen, and the corrosion of steel specimens immersed in the water.

Oxidation of cast-iron G. Nándori (*Koh. Lapok-Ontöde*, 1959, **10,** Feb.–March, 70–77) The author has investigated the effect of the atmosphere, air blast, and FeO containing slag on the oxygen content of cast iron.—P.K.

Dry oxidation, at elevated temperatures up to 1200°C, of steels and refractory alloys S. Ferré (*Rev. Mét.*, 1959, **56,** April, 386–394) Effects of oxidation on steels and heat-resistant alloys at temperatures up to 1200°C are examined and shown by isothermal curves and micrographs. Four stainless steels are included in the alloys investigated.

On the mechanism of oxidation at elevated temperatures of austenitic 18–8 steel J. Bénard, J. Hertz, Y. Jeannin, and J. Moreau (*Compt. Rend.*, 1959, **248,** April 6, 2095–2097) A slow parabolic period of preferential Cr oxidation is followed by a rapid breakdown of the film with deposition of α-Fe_2O_3. This stops almost completely when the layer impoverished in Cr is oxidized.

Apparatus for corrosion tests at elevated temperatures (*Fonderie*, 1959, Feb., 90–92) Specimens are placed in a stainless steel water bath in the corrosive liquid to be investigated, with electric heating elements thermostatically controlled through mercury relays to ±1°; temperatures of 25–95°C can be obtained.

The effect of structure factors on the corrosion of stainless steel N. A. Nielsen (*Werks. Korr.*, 1959, **10,** July, 429–442) Corrosion tests were made on a variety of stainless steels in which the attack at high temperatures and in boiling corrosive media was correlated with the microstructure of the alloy. The mechanism of corrosion attack is discussed in view of the very different corrosion behaviours of the various types of stainless steel.—T.G.

The application of the polarization curve to the study of pitting corrosion of stainless steels J. M. Defranoux (*Werks. Korr.*, 1959, **10,** July, 425–249) The mechanism of pitting corrosion of stainless steel is briefly reviewed and a new method of the study of corrosion based on measuring the polarization curve in aqueous media such as 4%NaCl solution is reported.

Physical properties of soil and their relation to the mechanism of the corrosion reactions of iron in the soil T. Marković (*Corros. Anticorros.*, 1958, **6,** Nov., 402–411) The physical properties of soil which affect the resistance to corrosion are discussed – particle size, capillary and non-capillary porosity, humidity, and air content and other factors – and the mechanism of iron corrosion in the soil is discussed, with results of a field test.

The effect of stabilization with niobium in the intracrystalline corrosion susceptibility of corrosion resistant 18/9 Cr–Ni steels V. Číhal and R. Pospíšil (*Hutn. Listy*, 1958, **13,** (12), 1092–1098) The cause of the burning of the steels on heating to high temperatures was found to be the solution of niobium carbide and the subsequent precipitation of $(Cr, Fe)_{23}C_6$ at grain boundaries. The influence of high austenitizing temperatures can be counteracted by stabilization at 850–950°C, when the niobium carbide reforms. Niobium present in amounts above the stoichiometric is shown to cause embrittlement by σ-phase formation; the mechanism is explained.—P.F.

Corrosion testing of paints with the help of aerosols H. Anders (*Werks. Korr.*, 1959, **10,** March, 151–152) A brief outline is given of the production and use of aerosols for testing the resistance of painted surfaces to corrosion. The equipment and the aerosols used are described.

Resistance to corrosion of aluminium coated steel wire E. T. Englehart and K. J. Brondyke (*Wire Wire Prod.*, 1958, **33,** Nov., 1365–1372, 1404–1405) Factors in the hot dip production of Al-coated steel which influence corrosion resistance are discussed. On the basis of a number of accelerated tests corrosion resistance is stated to be equal or superior to that of galvanized wire.—A.G.

Steels and alloys resistant in media of sulphuric and hydrochloric acids L. Colombier (*Usine Nouv.*, 1959, **15,** April 30, 97, 99; *Mét. Constr. Méc.*, 1959, **91,** March, 155–162; April, 249–259) A report of a conference on Dec. 10 1958. Most of the alloys considered were non-ferrous apart from some Co steels.

Investigation on the action of vapour-phase inhibitors L. Cavallaro and G. Mantovani

(*Werks. Korr.*, 1959, **10**, July, 422–425) The mechanism of corrosion protection by vapour-phase inhibitors is reviewed and the protection afforded on cast iron by such amines as octadecylamine, morpholine, etc., reported.

Steels resistant to sea water Thivin (*Usine Nour.*, 1959, **15**, May 7, 38) A report on a conference held on Dec. 10 1958. Parts for Kaplan turbines are discussed of carbon and 4%Cr steel and of bronze. Cathodic protection is also considered.

Corrosion and protection of iron and steel: a review of the literature published during 1954 and 1955 H. Steinrath and H. Ternes (*Stahl Eisen*, 1959, **79**, March 5, 307–313) The literature is reviewed under the headings: effect of composition; atmospheric corrosion; corrosion by town's grid, and natural gas; corrosion by water (including high-purity water) (194 refs).—T.G.

Corrosion and protection of iron and steel (Review of the literature published in 1954–55) H. Klas and G. Heim (*Stahl Eisen*, 1959, **79**, May 14, 731–737) In this final instalment of the series are reviewed: non-metallic inorganic coatings and organic coatings (refs. 801–987).

Protection against corrosion fatigue A. Royez and J. Pomey (*Rev. Mét.*, 1959, **56**, Feb., 122–128) The characteristics of corrosion fatigue are outlined, and the efficacy of various coatings as a protective measure is discussed. Compressive pre-stressing is effective under the right conditions in service.

Copper–nickel chromium and corrosion protection A. H. Du Rose and W. J. Pierce (*Met. Fin.*, 1959, **57**, Mar., 44–50, 54) Exposure and accelerated tests are reported on Cu, Ni and Cr plate on steel. The results are assessed and types of corrosion illustrated; testing methods for thickness, etc. are also considered.

Corrosion behaviour of some of the newer metals N. P. Inglis and J. B. Cotton (*Eng. Mat. Design*, 1959, **2**, Feb., 78–80) Surface passivation of stainless steel is referred to.

Results of stress corrosion tests on type 347 stainless steel in 500 F pH 10–11 lithium hydroxide G. E. Galonian (*KAPL–M–GEG–11*, 1958, May, pp.29; from *US Govt. Res. Rep.*, 1958, **30**, Nov. 14, 470. No abstract).

Influence of radiation upon corrosion and surface reactions of metals and alloys M. T. Simnad (*GA–130*, 1957, pp.28; from *Nuclear Sci. Abs.*, 1959, Mar. 31, (6a), 499) The usual corrosion mechanisms are considered in relation to the effects of light and X-rays. Corrosion of reactor materials in aqueous solutions and effects of irradiation or gas-solid reaction as well as proton irradiation effects are discussed.

Certain features of the cathode process on stainless steels in nitric acid solution E. N. Mirolyubov, M. M. Kurtepov, and N. D. Tomashov (*Doklady, AN*, 1959, **125**, (6), 1288–1291) Methods of obtaining cathodic polarization curves were applied to the study of cathode processes on rustless steels of chromium and chromo-nickel types. The relation between the velocity of corrosion, the strength of solutions and the nature of steel was also traced. The nature of the cathode processes is due to the disturbance of the passivity of steel. The influence of the products of self-solution is also traced.—S.I.T.

Mechanism of intercrystalline corrosion of stainless steel in nitric acid A. J. Krasil'shchikov, L. M. Volchkova, J. K. Burtseva, and V. D. Plyasunov (*Doklady AN*, 1959, **125**, (6), 1285–1287) The results of experiments of placing electrodes of stainless steel in nitric acid solutions of different strength, are given, and curves of strength of currents of differential depolarization in relation to the concentration difference and time, are drawn.—S.I.T.

Corrosion inhibitors in automotive coolants M. Levy (*Ind. Eng. Chem.*, 1959, **51**, Feb., 209–211) Polarization data are given for the solder and copper components of cast-iron radiators in the presence of a large number of inhibitor solutions.

Developments in cooling tower system treatments. I. Polyvalent ion-polyphosphate inhibitors J. I. Bregman and T. R. Newman (*Corrosion*, 1959, **15**, Feb., 97–100) The addition of certain metallic cations in very small quantities to synergized polyphosphate treatments in cooling-tower systems will increase corrosion protection. This new approach is considered in detail with accompanying laboratory and field data. The theoretical reasons for the effect of metal cations have yet to be established. It is likely, however, that cathodic inhibitors such as Zn may help to prevent the formation of local cells at points on the metal surface where potential differences exist.—T.G.

A constant temperature corrosion probe R. W. Kear (*J. Inst. Fuel*, 1959, preprint, pp.7) The instrument is specially designed for flue gas studies and its use for full-scale boiler and laboratory tests is described.

The evaluation of certain organic nitrogen compounds as corrosion inhibitors E. J. Schwoegler and L. U. Berman (*Corrosion*, 1959, **15**, Mar., 128–130) The static water drop test is used for the testing of various heterocyclic compounds dissolved in lubricants. Corrosion inhibiting effect is related to the presence of hydrogen-substituted heterocyclic N atoms and replacement of these removes the effect. *N*-hydroxyalkyl derivatives in synthetic di-ester oil, but not in petroleum oil, were effective in a manner related to the position of the —OH group, being more effective the closer it came to the N-atom.

Corrosion inhibitor testing inside a products pipe line R. H. Meyer (*Corrosion*, 1959, **15**, Mar., 131–134) Four inhibitors were tested by 7 procedures in a 151 mile section of an oil pipe line. The test coupon method is recommended. One inhibitor produced a bulky product which clogged the strainer. X-Ray examination of the filter residues was one method of corrosion evaluation.

Control of internal corrosion of petroleum products pipelines with oil-soluble inhibitors M. R. Barusch, L. S. Haskell, and R. L. Piehl (*Corrosion*, 1959, **15**, Mar., 158–166) The substitution of oil-soluble inhibitors for aqueous $NaNO_2$ is described and the programme which has reduced corrosion rates to an average of only 0·025 mil/year is given. A mechanism for the internal protection process is advanced and also the effects of using more than one inhibitor.

Experiences with sodium nitrite: unpredictable corrosion inhibitor S. Sussman, O. Nowakowski, and J. J. Constantino (*Ind. Eng. Chem.*, 1959, **51**, Apr., 581–584) High sulphate concentration and other unidentified factors adversely affect the inhibiting action of $NaNO_2$.

The 6 types of corrosion—A preventive guide P. C. Noy (*Prod. Eng.*, 1959, **30**, Mar. 2, 67–69) A brief account is given with examples and methods of prevention of the following types of corrosion: direct attack, complex attack, galvanic action, concentration cell, dezincification and fatigue and stress corrosion.

The water engineer and cathodic protection K. A. Spencer (*Fuel Economy Rev.*, 1959, **37**, 101–112) The protection of underground pipes by bituminous-type coatings and cathodic protection is discussed.

Cathodic protection of process equipment NACE Task Group T–3G–3 (*Corrosion*, 1959, **15**, Mar., 123–124) Protection of mild and stainless steel in the chemical industry is described, among other examples.

The prevention of steel stack corrosion and smut emission with oil-fired boilers H. A. Blum, B. Lees, and L. K. Rendle (*J. Inst. Fuel*, 1959, **32**, Apr., 165–171) A connexion between corrosion and smut emission has been established. Keeping surface temperature above 120 C by lagging and shielding from wind and rain largely prevents both. It is most easily effected by surrounding with an Al sheath leaving a $\frac{1}{4}$ in. radial gap.

Cathodic protection of water storage tanks at Kalamazoo, Mich. A. Sabo (*J. Am. Water Works Assoc.*, 1959, **51**, Feb., 200–204) A general discussion of principles and an account of the protection of tanks of 750000, 350000 and 500000 gal. capacity, with costs, are given.

Seaguard cathodic protection (*Shipbuilder*, 1959, **66**, Mar., 153–154) The fittings of the oil-tanker British Ambassador are described.

Experiments with a trailing platinum anode D. Spector, H. S. Preiser, and D. Khoushy (*Corr. Tech.*, 1959, **6**, May, 143–148) Tests on 10000 t ship during a voyage from Haifa to New York are reported.

Cathodic protection applications using platinum anodes H. S. Preiser (*Platinum Met. Rev.*, 1959, **3**, Apr., 38–43) Various uses of Pt-clad Ta and Ti anodes are considered, including ship protection. **Lead-platinum Bi-electrodes** L. L. Shreir (44–46) Introduction of a micro-electrode of Pt into a lead anode is shown to favour production of a peroxide coating and to prevent corrosion of the Pb by chlorides. **Electrochemical properties of the platinum metals. A new approach to studies of corrosion resistance and cathodic protection** M. J. N. Pourbaix, J. Van Muylder, and N. de Zoubov (47–53) Potential-pH diagrams are constructed and used to predict conditions producing corrosion. The mechanism of electrochemical attack on Pt in water is discussed.

ANALYSIS

Photometric titration of iron with ethylenediaminedi-(*o*-hydroxyphenylacetic acid) A. L. Underwood (*Anal. Chim. Acta.*, 1959, **20**, Mar., 228–232) Up to 1 mg Fe^{3+} in 100 ml solution is titrated at pH 3·5 with the above reagent, using a photometric end-point. Possible interferences are investigated.

Rapid chemical analysis of cast iron F. Sterbenz (*Koh. Lapok-Ontöde*, 1959, **10**, Jan., 11–16) Rapid analytical methods, used in a Hungarian iron foundry, for determination of Si, Mn, P, Cr, and Ni in cast iron are described.—P.K.

Contribution to chemistry in iron and steel works: sample taking and estimation of hydrogen in steel (1953–58) A. Stetter (*Stahl Eisen*, 1959, **79**, July 23, 1087–1090) A review with 31 refs.—T.G.

The electronic thermo-balance and its application in the iron and steel works laboratory R. Strubl (*Stahl Eisen*, 1959, **79**, March 5, 298–303) The author reviews the work of the Czechoslovak Akademy of Science on the development of an automatic electronic thermo-balance for use in iron and steel works laboratories and describes the equipment including a furnace and a gas-analysis apparatus. Several examples of application are given (79 refs).—T.G.

Sampling liquid steel for hydrogen J. G. Bassett (*AIMME, Proc. O.H. Comm.*, 1958, **41**, 80–89) The author describes a method of obtaining a steel sample for H_2 content directly from the bath. It involves the use of an evacuated Pyrex tube containing a copper mould. The technique is compared with the Taylor sampler and the Geffner pin tube and is shown to give consistently higher H_2 contents. The use of the sampler in studying trends of H_2 in acid OH steel is reported.—G.F.

The determination of trace elements N. W. H. Addink (*JISI*, 1960, **194**, Feb., 199–210) [This issue].

Analytical applications of the 'Chelons'. VIII. Spectrophotometric and absorptiometric micro-determination of iron with 1:2-diamino-*cyclo*hexanetetra-acetic acid (ADCT)). F Bermejo Martínez and R. Rey Mendoza (*Anal. Real Soc. Espan. Fis. Quim.*, 1959, **55**(B), April, 293–298 [In Spanish] A report of one of a series of investigations of the behaviour of coloured cations in the presence of ACDT is given and, as a consequence, a new method for the determination of iron with ADCT–Na_2 is established. Full details of the analytical procedure are given. The light absorption of the chelonate, ADCT–Fe(III), is a linear function of concentration over the range 30 to 250 μg Fe/ml. The chelonate was found to be stable for at least 10 days at pH4 and the intensity of the absorption was found to vary little in the pH 2–9 range. **X. Iodometric determination of ferrous iron in the presence of 1:2-diamino-*cyclo*hexane-tetra-acetic acid (ADCT)** (305–308) Full analytical details of this new method are given: the results compare well with the dichromate method. Essentially, it consists of a thiosulphate titration after adding 5%ADCT–Na_2 solution to the ferrous iron solution and adjusting the pH to 6. In the first part of the article, a new normal potential, E_0^1, for the system $FeY'^{-1} + 1e^- + FeY'^{-2}$ is established and at pH = 6, Eo^1 is found to be

0·10 V. The variation of the oxidation potential of the system FeY^{-1}/FeY^{-2} with pH was also studied and found to be linear. Solutions of ADCT–Fe(II) were found to be stable indefinitely in inert atmospheres.—P.S.

Determination of silicon in ferrosilicon by a titration method S. Král and J. Sedlář (*Hutn. Listy*, 1958, **13,** (9), 812) Two methods of determining Si in Fe–Si were checked against the standard gravimetric analysis. The method proposed by Velken (*JISI*, 1958) was found to give low results, that of Kysil (*Hutnik*, 1952, **2,** 7–8, 180) agreed with the gravimetric estimations.—P.F.

The selective determination of nickel with *cyclo*hexanedione dioxime D. Monnier and W. Haerdi (*Anal. Chim. Acta.*, 1959, **20,** May, 444–455) Microgram quantities are determined by solvent extraction of the coordination complex.

Determination of total sulphur content A. A. Fedorov and A. M. Krichevskaya (*USSR Patent*, 579913, 1957, July 3; from *Techn. Translations*, 1959, **1,** April 3, 214) The sample is dissolved or fused and SO_4 is reduced with metallic Cr in H_3PO_4 under an inert gas. H_2S is collected in cold Na_2S soln. and determined with dimethyl-*p*-phenylenediamine in presence of Fe perchlorate.

Studies on the determination of carbon and sulphur in various ferro-alloys by the use of high frequency induction furnace H. Goto, T. Watanabe, and K. Suzuki (*Nippon Kinzoku*, 1958, **22,** May, 233–236) Rapid determinations in Fe–V, Fe–W, Fe–Cr, and Fe–Mn, and determinations of S in Fe–Si, Fe–Ti, magnetite and hematite can be made if an accelerator is used to produce complete combustion of the alloys. Suitable substances are Fe, Cu, Sn, Cr_2O_3 CuO, NiO, Co_3O_4 and MnO_2.—K.E.J.

Separation of titanium from accompanying elements by the method of ion-exchange chromatography. Communication 3: separation of titanium and zirconium T. A. Belyavskaya, I. P. Alimarin, and I. F. Kolosova (*Zhur. Anal. Khim.*, 1958, **13,** (6, 668–670) Ti and Zr are separated chromatographically, over a wide range of ratios, by means of HCl on a cation exchange resin.

Determination of vanadium and chromium by the photometric titration method V. F. Barkovskii (*Zhir. Anal. Khim.*, 1958, **13,** (6), 682–685) An apparatus and method are described for the photometric titration of V and Cr in Fe–V and steels without the use of an indicator. A P–W–V complex can be used for determining V and Cr in free-cutting steels without separating W.

Coulometric titration with quinquevalent uranium. Determination of vanadium (V) S. L. Phillips and D. M. Kern (*Anal. Chim. Acta*, 1959, **20,** March, 295–298) V^{5+} is titrated amperometrically at pH 1·2·5 in concentration down to 15 γ, using generated U^{5+}. Fe^{3+} is reduced simultaneously.

Rutin as an inorganic analytical reagent. II. Detection of vanadium (V) with rutin P. Szarvas and Z. Jarabin (*Anal. Chim. Acta*, 1959, **20,** April, 330–331) [In German] The detection of V^{5+} is based on the colour reaction with rutin (quercetin-3-rutinoside); the orange-red colour is detectable down to 0·3 γ V^{5+} in 1 ml solution.

The determination of nickel, cobalt, iron, and zinc in ferrites D. H. Wilkins (*Anal. Chim. Acta*, 1959, **20,** March, 271–273) Ni, Co, Fe, and Zn are separated on a strongly basic anion-exchange resin, and determined by back titration of excess EDTA.

Rapid analysis of the chromium bath: complexometry, ion exchangers R. Weiner, E. Ney, and C. Schiele (*Metalloberfläche*, 1959, **13,** Jan., 5–7) The rapid determination of chromic ions in Cr plating baths is discussed; a complexometric titration can be used, with a preliminary separation from chromic acid if necessary, using an amberlite IRA 140 ion exchange column.

Critical studies on various methods for the determination of iron in ferrites and rapid complexometry of iron, manganese, and zinc in ferrites H. Kitagawa and Y. Aimoto (*Nippon Kinzoku*, 1958, **22,** Aug., 389–393) Optimum conditions are described for methods using reduction by Zn amalgam and $KMnO_4$ titration; photochemical reduction by formic acid and H_3VO_4 titration; and reduction by $SnCl_2$ and H_3VO_4. The rapid simultaneous complexometry of Mn and Zn in Mn–Zn-ferrite is described.—K.E.J.

Study on a fractional vacuum fusion method for the determination of the constituent oxide in steel S. Maekawa, Y. Nakagawa, and M. Shudo (*Tetsu to Hagane*, 1958, **44,** Dec., 1382–1387) Studies were made on prepared specimens containing pairs of oxides chosen from FeO, Al_2O_3, SiO_2, and MnO. The total oxygen from the vacuum fusion method agrees with the sum from the residue method but not from the fractional method. Each oxide does not agree with that from the residue method. The method cannot be used on its own.

Study on the chemical analysis of sand iron and ilmenite. III. Determination of MnO, CaO, MgO, and P_2O_5 S. Wakamatsu (*Tetsu to Hagane*, 1958, **44,** Dec., 1387–1392) MnO is determined by photometric or volumetric methods, using $(NH_4)_2S_2O_8$. CaO and MgO are determined using EDTA titration. P_2O_5 is determined photometrically with molybdenum blue.—K.E.J.

Rapid flame-photometric analysis of blast furnace slag K. E. Stumpf and T. Gonsior (*Rev. Univ. Mines*, 1959, **15,** May, 404) A brief note on Ca and Mg determination.

The influence of the metallic state on spectral emissions from carbon steels A. Camuñas (*Rev. Univ. Mines*, 1959, **15,** May, 313–315) The effects of transformations such as martensite decomposition on C determinations are considered.

The spectrographic determination of residual elements in steel by the excitation index technique K. M. Bills (*JISI*, 1960, **194,** Feb., 193–198) [This issue].

Spectrographic determination of carbon and sulphur in industrial control V. Mathieu, M. Lacomble, and L. Charlet (*Rev. Univ. Mines*, 1959, **15,** May, 597–598) Uses in the iron and steel industry are briefly described.

Automatic spectrometric determination of phosphorus and the usual accompanying elements in steel by absorption and by excitation G. Graue, S. Eckhard, and R. Marotz (*Rev. Univ. Mines*, 1959, **15,** May, 290–296) [In German] Determination of C, S, P, and Mn is considered; also of Al, Si, Cr, Cu, and Sn.

Testing materials with high-frequency spectroscopy A. Lösche (*Materialprüfung*, 1959, **1,** March 20, 79–86) The principles of RF spectroscopy are outlined, and applications to materials testing in the fields of crystal physics, plastics, etc. are described (20 refs).

Three years' experience of spectrometric analysis in the MBLE installations, Macq V. Mathieu, M. Lacomble, and L. Charlet (*Rev. Univ. Mines, Monographies Industrielles*, 1959, **15,** May, 8) Determinations of Mn, Si, P, Cu, Sn, Ni, Cr, Al, and Mo are considered.

The Spectrovide, a new vacuum spectrometer for steelworks production control M. de Belder (*Rev. Univ. Mines*, 1959, **15,** May, *Monographies Industrielle*, pp 2) A description of the apparatus and its use for the determination of C, S, and P.

From the practice of X-ray spectrographic analysis G. Lang (*Materialprüfung*, 1959, **1,** March 20, 109–110) A note on improving the homogeneity of specimens and on vacuum equipment for determining elements with atomic numbers less than 20.

Note on the analysis of small quantities of material by X-ray fluorescence N. W. H. Addink (*Rev. Univ. Mines*, 1959, **15,** May, 530–532) [In English] Comparison with spectrochemical methods are made for Fe, Ni, and Cr. A wide range of oxides (or ions) is also covered.

Methods of qualitative analysis with X-ray fluorescence. Researches on niobium in complex ores M. Maricc (*Rev. Univ. Mines*, 1959, **15,** May, 555–558).

X-ray fluorescence analysis of powders F. J. Haftka (*Rev. Univ. Mines*, 1959, **15,** May, 549–555) [In German] Methods are described and the determinations of Fe in various combinations, and in the Fe–Cu system are presented.

The mutual influence exerted by alloy components in X-ray fluorescence analysis H. Neff (*Materialprüfung*, 1959, **1,** March 20, 108–109) Nomograms are developed for determining the mass extinction coefficients in Cr–Ni steels for Mo–Kα, Cr–Kα, and Ni–Kα radiation.

The K-absorption edge of iron in the α- and σ-phases of the Fe–Cr system V. A. Kazantzev (*Doklady AN*, 1959, **124,** (4), 806–807) This paper marks the completion of a series of studies by the author on the α–σ phase transformations in Fe–Cr alloys. It is concluded that the K-edge of iron on α–σ phase transformation is displaced towards higher energy values. Certain conclusions are also reached regarding the 3*d*-band and the 4*sp*-band, and it is suggested that the phase transformation is determined by the redistribution of occupied and unoccupied electron levels in the 3*d* and 4*sp* states.—S.I.T.

The isotopes laboratory of the Bundesanstalt für Materialprüfung, Berlin-Dahlem R. Neider (*Materialprüfung*, 1959, **1,** March 20, 113–115) Reference is made to the increasing use of radioisotopes in material testing, safety measures, and the layout and equipment of the isotopes laboratory.

Iron analysis in chromium solutions A. Salka (*Met. Fin.*, 1958, **56,** Dec., 64) The iron is separated as ferric phosphate and determined by complexometric EDTA titration with ferron as indicator. The end-point is very sharp, thus accuracy and precision are very high. The estimation takes usually less than 20 min.—T.G.

Quantitative analysis of trace amounts of tin in steel by means of X-ray fluorescence T. S. Whitehouse (*Proc. 7th Conf. Ind. Applications of X-ray analysis* 1958, 257–260) A method using a pulse height analyser is described which can be used to determine Sn as low as 0·01% to ± ·003%.

Rapid analysis of chromite and chrome ore J. I. Dinnin (*US Geol. Survey Bull.*, 1084-B, 1959, pp.31–68) Fusion with Na_2O_2 and volumetric determination of major and spectrophotometric determination of minor constituents are described.

Analysis for zinc, cadmium and copper in electroplating waste effluents F. Stevens and L. E. Lancy (*Plating*, 1958, **45,** Aug., 832–834) The method is sensitive for Zn and Cd at concentrations of 0·5–50 p.p.m. The usual heavy metals present in waste samples such as Cu, Fe, and Ni will not interfere. For Cu, a spot test is suggested which allows estimation in the range 0·1–5 p.p.m. No interference occurs with relatively high concentrations of other possible cations.—T.G.

Flame spectrophotometric determination of calcium in cast iron H. Goto, S. Ikeda, and J. Kimura (*Nippon Kinzoku*, 1958, **22,** Apr., 185–187) Iron is first extracted as chloride with amyl acetate. Ca is then determined either by comparison with a calibration chart or by the addition method; the emission intensity is measured at 554 mμ. Rapid, reproducible results are obtained with more than 0·01% Ca.

Rapid analysis of alloying elements in iron and steel by photoelectric colorimeter. II. H. Kato and T. Matsumura (*Toyo Kohan*, 1953, June, 54–58) Various aspects of the analysis for copper are examined. For manganese, the solution from determination of copper can be used. For phosphorus, the procedure is improved to eliminate difficulties from the iron colour.—K.E.J.

INDUSTRIAL USES AND APPLICATIONS

A study of the metallurgical properties that are necessary for satisfactory bearing performance and the development of improved bearing alloys for service up to 1000°F T. V. Philip, A. E. Nehrenberg, and G. Steven (*WADC-TR-57-343, Pt. II; AD-203824*, 1958, Sept., pp.63; from *Nuclear Sci. Abs.*, 1959, **13,** Mar. 31, 502–503) A steel with the composition 1·09%C, 4·2%Cr, 1·9%V, 6·7%W, 3·7%Mo and 5·2%Co is recommended from trials on 51 experimental steels. It should be austenitized at 2225°F, oil-quenched and tempered for two consecutive 2-h periods at 1050°F.

Development of iron-aluminium base alloys for gas-cooled reactor components F. Tate (*MND-DB-2523, Quart. Progress Report No.3*, 1958, Sept., pp.41; from *Nuclear Sci Abs.*,

1959, **13,** Jan. 31, 95) Additions of Zr, Nb and Mo increase stress rupture life, Zr decreases oxidation resistance at 1650° and 1800°F and Nb had a beneficial effect. Room temp. ductility is decreased by Zr and Nb.

Developments of ferritic stainless steel–UO_2 dispersion fuel elements W. K. Barney *et al.* (*KAPL*–1908, 1958, Jan., pp.16; from *US Govt. Res. Rep.*, 1958, Dec. 12, 633. No abstract).

Structural uses of welded high-tensile steel G. Roberts (*J. West Scot. ISI*, 1958–59, **66,** 122–130) Chemical and physical properties and design characteristics are given. Examples of recent structures and the saving in weight possible are instanced.

The application of tubes to structures G. B. Godfrey (*J. West Scot. ISI*, 1958–59, **66,** 104–121) Choice of steel for tubes and design factors for structures are considered. Weight savings by the use of tubes may amount to 30–50%.

Weight saving in military steel bridges A. E. Long (*J. West Scot. ISI*, 1958–59, **66,** 131–150) The possible advantages of high-tensile steel are noted.

The applications of low-alloy high-tensile steel I. M. Mackenzie (*J. West Scot. ISI*, 1958–59, **66,** 93–103) Properties, availability, and fabrication are discussed and the reasons for the relatively small demand for steels of this type are considered.

Replacement of high-manganese Hadfield steel for section casting by graphitic steel N. F. Dubrov (*Stal'*, 1959, (6), 506) A note from the Ural Research Institute for Ferrous Metals. Hypoeutectic steel is recommended for linings in crushing, grinding, and mixing equipment.

Service temperature of steel for flat springs in steam turbine labyrinth seals increased to 640°C T. I. Volkova (*Metallov. Obra. Met.*, 1958, June, 21–25) The compositions of the steels, their mechanical properties and relaxation test results are tabulated. Spring steels can be chosen from the data given for operations at 400–640°C for 10,000 h.

Upright metal members: Strains permitted in various countries C. Jeż-Gala (*Acier-Stahl-Steel*, 1959, **24,** April, 191–197) Comparisons of British Czech, Russian, US, Austrian, Belgian, French, Italian, German, and Swiss practice.

Steel silos T. Lo Monaco (*Acier-Stahl-Steel*, 1959, **24,** April, 188–190) A prefabricated design is included.

Prefabricated wall elements of galvanized steel sheet for a German building exhibition W. Hettich (*Acier-Stahl-Steel* 1959, **24,** April, 173–177).

Realisations of the first French line of gas-filled cable in steel tubing Société Alsacienne de Constructions Méchaniques (*Usine Nouv.*, 1959, **15,** March 12, 98–99, 101; from *Bull. Soc. Alsacienne*, 1957, Jan.–Oct.) An illustrated account of the elements of the cable and its laying.

Experience with corrosion-resistant chromized steel screws E. Taubert (*Draht*, 1959, **9,** Dec., 505–507).

HISTORICAL

Metallographic studies of prehistoric and ancient iron objects found in Czechoslovakia R. Pleiner (*Stahl Eisen*, 1959, **79,** March 5, 294–298) The results of metallographic studies of about fifty objects found in Czechoslovakia are reported. They cover the time from the La-Tène period to the XIIth century and are mainly concerned with the manufacture of blades and their microstructures.—T.G.

The replacement of forgings by iron castings during the 14th and 15th centuries J. Piaskowski (*Prz. Odlew.*, 1959, **9,** (1), 16–18) Metallurgical investigation of iron articles from Danzig has shown that as early as the fourteenth and fifteenth centuries forgings were replaced by iron castings (i.e. from pig iron smelted in a blast furnace). The pommel of a sword from the late Middle Ages, probably made in Western Europe, was cast in iron containing 3·15%C, 2·09%Si, 0·45%Mn, 1·13%P and 0·136%S. Casting of the pommel was most probably carried out by the lost wax method; it showed no internal faults and its dimensions reveal a high accuracy of production. The use of pig iron from a blast furnace in place of a wrought iron forging resulted in a great saving in metal, over 30%, because it avoided the loss of metal caused by burning during the production of refined iron.—M.T.

Discoveries on the history of iron in the Ahrweiler Forest O. Kleemann (*Stahl Eisen*, 1959, **79,** July 23, 1087) This is a résumé of a lecture given by J. Lilienthal on the discovery of early-history iron smelters in the river Ahr district in Western Germany. It is intended to make a thorough study of the findings.—T.G.

Archduke John and his impact on the Styrian mining industry H. Apfelbeck (*Berg. Hütten. Monats.*, 1959, **104,** May, 94–99) R. Walzel (100–115) In commemoration of the centenary of the death of the Archduke John the author reviews the history of the Styrian iron and steel industry which was founded in the early nineteenth century by the Archduke after he had visited the industry in Great Britain. He also founded the Montanistische Hochschule (40 refs).—T.G.

The 120th anniversary of the Třinec Iron and Steelworks J. Lampa and J. Šunkala (*Hutnik*, 1959, **9,** (4), 113–114) An historical survey is given, with special emphasis on recent developments in the production of rails, coal-cutter components, etc.—P.F.

The 120th anniversary of the Třinec Steelworks V. Janota (*Slévárenství*, 1959, **7,** (4), 127–131) An historical survey of developments and achievements in the production of cast iron and cast steel.—P.F.

The history of magnesite F. Czedik-Eysenberg (*Berg. Hütten. Monats.*, 1959, **104,** May, 118–122) The history of the Austrian magnesite industry, which runs parallel to the growth of the Styrian iron and steel industry, is briefly reviewed.—T.G.

The 130th anniversary of the Klement Gottwald Steelworks in Vitkovice (*Hutnik*, 1958, **8,** (12), 393–395) An historical survey of the development of these large steelworks in the Ostrava region is made.—P.F.

The scientific work on steel by Professor Eduard Maurer W. Bischof (*Neue Hütte*, 1959, **4,** May, 258–266) A description of the published work of Professor Maurer and coworkers in ferrous metallurgy is followed by a bibliography in chronological order (68 refs) and a list of publications of the Eisen-Forschungsinstitut Henningsdorf (31 refs).

Sidney Gilchrist Thomas T. G. Grey-Davies (*J. Monmouthshire Local History Council*, 1959, (7), 11–12) A note on his work at Blaenavon.

Abraham Darby and the coke-smelting process M. W. Flinn (*Economica*, 1959, Feb., 54–59) A critical examination of the view that Darby first used coke for smelting iron in 1709. Until further evidence is presented it is impossible to be more precise than that the latter part of the period 1709–1717 is the date.

The growth of the English iron industry 1660–1760 M. W. Flinn (*Economic History Review*, 1958, **11,** (1), 144–153) A revision of the view that the condition of the iron industry in the century before 1760 was one of stagnation or decline. It was a high-cost industry and prices maintained by a fairly high tariff kept it profitable. Although there were important regional changes and short-term fluctuations a steadily rising demand encouraged continuous if limited expansion, slow at first but more rapid after 1710.

Sacrificial offerings made of iron J. M. Ritz (*Stahl Eisen*, 1959, **79,** June 25, 934–940) An illustrated historical account.—T.G.

America and steel–Growing together B. J. Fairless (*AISI Yearbook*, 1957, 51–58) An address. Historical and statistical.

ECONOMICS AND STATISTICS

The steel industry metals: Iron and steel J. H. Thompson (*Min. J.*, 1959, *Annual Review No.*, May, 29, 31). **Manganese** S. Bracewell (33,45). **Nickel** (35). **Cobalt** (37). **Chromium** (37, 38, 39). **Tungsten** (39). **Molybdenum** (39, 41). **Vanadium** (41). **Niobium and Tantalum** (41). Industrial notes and statistics.

Canada's steel to double in two decades J. Convey (*Can. Metalw.*, 1959, **22,** Jan., 18–19) By 1980, Canada's primary consumption of steel is expected to be between 14 and 16 million tons per year, as compared with 7·6 million tons in 1957. Details are given of the Canadian industry's expansion schemes.—G.F.

A graphical method of solving multiple correlation analyses of metallurgical production problems R. Vojta (*Hutn. Listy*, 1958, **13,** (9), 795–800) A simple graphical method is developed and illustrated by application to the problem of determining the most important factors affecting the time of melt required for a standard OH tube steel.—P.F.

Trade position in the wire industry (*Draht*, 1959, **10,** April, 131) The reduced demand for wire products in 1958 and its causes are discussed in this outline report of the Annual Meeting of Fachvereinigung Draht at Düsseldorf in March 1959.

Time allowances and control of production in grinding and descaling of billets based on statistical evaluation of actual output J. Wolf (*Stahl Eisen*, 1959, **79,** July 23, 1075–1079) Statistical. An internal accountancy system is explained.—T.G.

MISCELLANEOUS

Improving manganese metal production V. S. Zel'din and L. G. Ilyushina (*Stal'*, 1959, (4), 333–335) The production from slag by reduction with Si–Mn is described, the development of the process being traced from the original use of Si. A tilting furnace is used.

Conference on computers in the iron and steel industry (BISRA, 1958, 64) **Introduction** S. Beer (5–7). **Experience in using a computer for payroll** J. S. Pugh (8–12, discussion 12–15). **A simulation of melting shop operations by means of a computer** R. Neate and W. J. Dacey (16–28, discussion 28–31) Applications of Monte Carlo methods to the operation of a 100-t OH furnace as related to O_2 enrichment during charging and to melting shop procedures is described **The use of a computer in a rolling mill office** R. G. Massey (32–40, discussion 40–43) An experimental study carried out by BISRA is described. In discussion the time needed for programming and other topics were elucidated. **Training for computers** D. G. Owen (44–47, discussion 47–51). **Demonstration of the BISRA 'Pegasus' computer** (52–59). **Glossary of digital computer terms** (60–61).

Towards a further increase in labour productivity in the iron and steel industry (*Stal'*, 195, (6), 481–484) An editorial, tracing the increase of labour productivity, particularly in blast furnace operation, in the USSR, but with notes on OH shops and rolling mills.

Experience of work in a production and labour organization department B. B. Rozin and R. S. Geifman (*Stal'*, 1959, (5), 462–464).

Prevention of accidents and health protection in blast-furnace and open-hearth operation A. Prókay (*PACT*, 1959, **13,** April, 92–97, 103) A translation of a Hungarian report on the hazards associated with blast-furnace and OH practice, and measures taken to prevent accidents, and to safeguard against the effects of heat and the toxic action of gas and other agents. The first section deals with ore preparation and blast-furnace practice.

On manganese poisoning in a steel melting factory and a load-test of manganese K. Ueno and S. Ohara (*J. Lab. Hyg. Iron Steel Ind.*, 1958, **7,** Nov., 3–12) [In Japanese] Manganese concentrations in the atmosphere and from workers' urine are given for a Mn mine, a workshop using Fe–Mn, and two shops melting Mn-steel. The highest figures were found in the workshop, but do not appear to represent a serious health hazard (74 refs).—K.E.J.

On spinal diseases of the employees in an iron and steel industry S. Kasai, Y. Okada, Y. Oga, E. Masaki, T. Sasamoto, M. Yoshida, E. Hayashi, and T. Fukushima (*J. Lab. Hyg. Iron Steel Ind.*, 1958, **7,** Nov., 13–19) [In English] Medical data for 1949–57 from the Hirohata Works of the Fuji Iron & Steel Co. Ltd, are given. Diseases such as *caries vertebrae* and *spondylitis deformans* occur slowly, and often without conscious symptoms. Spinal diseases are often found in an advanced stage, with only mild symptoms of backache or lumbago. No real cause or diagnosis can readily be suggested.—K.E.J.

Studies on professional aptitude tests for employee selection in iron and steel works Y. Kazui (*J. Lab. Hyg. Iron Steel Ind.*, 1958, **7,** Nov., 20–26) [In Japanese] New testin

methods are suggested. A result of 'P' from the Uchida–Kraepelius test usually indicates poor work. Men of aggressive, egocentric natures have excellent work records, but are poor in human relationships.—K.E.J.

On the method of the stepped blood cell count as a screening test I. Watanabe (*J. Lab. Hyg. Iron Steel Ind.*, 1958, **7,** Nov., 39–44) [In Japanese] The test and procedure for the method are described. It is used in conjunction with a general clinical examination in dealing with occupational disease.—K.E.J.

'Random-check-delay study' or 'work sampling' and its application L. Weber (*Stahl Eisen*, 1959, **79,** May 28, 802–811) This time-study method (called 'Multimoment' in German) is explained in detail and its great advantages as compared with other time-study methods stressed. However, the author mentions that these great advantages are not so obvious in the iron and steel industry as in other industries.—T.G.

A survey of the metal industry with special reference to research C. Blazey (*Austral. Eng.*, 1958, **50,** July 7, 48–56) The author deals with the production, distribution, and consumption of metals, describing the main stages through which passes the great bulk of metal produced each year. The ultimate objectives of research in the metal industry are discussed, and attention is given to the part played by fundamental research.—G.F.

Labour productivity indices in primary metallurgical works B. B. Rozin and R. S. Geifman (*Stal'*, 1959, (2), 167–169) A general productivity index for comparison of different installations is discussed.

The importance of the selection of the personnel and of the design of the plant for the co-operation of man and machine W. Fuchs (*Stahl Eisen*, 1959, **79,** May 28, 811–814) An analysis; automation for relieving the strain on human beings is emphasized.—T.G.

Accident prevention in the iron and steel industry H. Steeg (*Stahl Eisen*, 1959, **79,** May 14, 719–724) Accident prevention in iron and steel works during the last 14 years is reviewed and a number of examples quoted. The role of the safety engineer is stressed.

Improved accident prevention by taking account of the inadequacy of the human element H. Fischer (*Stahl Eisen*, 1959, **79,** June 11, 874–880) The inadequacy of the human element with regards to accidents is stressed and methods for prevention are advocated that take care of this inadequacy, most effectively by eliminating it.—T.G.

The variation of superstructure in iron selenide Fe_3Se_3 A. Okazaki (*J. Phys. Soc. Japan*, 1959, **14,** Jan., 112–113) Hexagonal and triclinic forms are observed. A third structure appears at 320°C.

Investigations on 'active iron'. Part I. Isolation G. V. L. N. Murty (*Metallurgia*, 1959, **59,** Mar., 141–142) Previous work on iron–water reactions is reviewed, and electrolytic conditions are set out for depositing 'active iron'—i.e. iron deposited under certain conditions, which is said to possess unusually high chemical reactivity.

BOOK NOTICES

BARNETT, O. T. '*Filler Metals for Joining*'. 9×6 in., pp.244. Illustrated. 1959, New York, London: Reinhold Corporation; Chapman and Hall Ltd. (Price £2 16*s.*)

This work, essentially an American workshop manual, sets out to present a guide to the selection of the 'proper filler metal for any joining situation'. It is a novel approach in welding literature to base a book on the filler metal rather than the metal to be joined and the author leans heavily on American specifications and information derived from manufacturers in the United States. Unfortunately, no British equivalents are given. Because of the excessive overlapping detail which would be involved, the author has chosen not to list all the filler metals and discuss them one by one but to classify filler metals under three main processes: welding and (more briefly) brazing and soldering. The filler metals are then discussed according to base metal group and process. Such a compilation undoubtedly has its uses and some outstanding chapters deal with the new iron powder electrodes, tungsten electrodes, and recent developments in surfacing. It is difficult, however, to judge the basis (or the significance) of 'relative popularity' tables of sizes of electrodes which are given throughout the work.
M. L. PEARL.

BRITISH CAST IRON RESEARCH ASSOCIATION. '*Selected Methods of Analysis of Foundry Materials*'. Part I. Pig Iron and Cast Iron. 9½×6 in., pp.97. Illustrated. 1959, Alvechurch: The Association. (Price, Members 12*s.* 6*d.*; Non-Members 17*s.* 6*d.*)

The BCIRA Methods of Analysis Sub-Committee was initiated in 1950 and since then a great deal of co-operative experimental work has been carried out by its members. Some of the recommended procedures have already been published in the *BCIRA Journal of Research and Development* but this simple and inexpensive laboratory manual is the first combined published result of this effort. It is not, of course, intended to replace the more fundamental and theoretical '*Chemical Analysis of Cast Iron and Foundry Materials*', (1951) by Westwood and Mayor, a new edition of which is being prepared. The manual deals with practical aspects of the sampling and analysis of pig and cast irons for carbon, silicon, manganese, sulphur, phosphorus, nickel, chromium, molybdenum, copper, titanium, and vanadium. Sections on spectrophotometric methods, laboratory equipment, apparatus, and reagents and laboratory techniques are also included. Later parts will deal with the analysis of alloy cast irons and ferro-alloys; slags, refractories, and fuels; and methods for residual elements. A pleasing touch is provided by binding the manual in plastic covers said to be resistant to acids, alkalis, and the commoner organic solvents.—M. L. PEARL.

GOUX, C. '*Guide de Thermometrie*'. 9½×6 in., pp.232. Illustrated. 1959, Paris: Eyrolles; Gautier-Villars. (Price 2600 Fr.)

This book is intended as a guide to engineers and research workers who are not specialists in temperature measurement. It therefore contains no theoretical treatments but provides a logical development of the subject and a comprehensive discussion o the essentials of choice of method to be employed and the techniques of application.

Part I comprises a brief review of the possible methods of measurement and Part 2 describes the various temperature scales including the detailed recommendations of the International Temperature Scale of 1948, with amendments of 1952. Very few engineers are aware of this practical scale and one very rarely hears the name Celsius used in this country. Part 3 discusses at length the choice of the pyrometric method from aspects of accuracy, reproducibility, accessibility of location to be studied etc. The longest part of the book, Part 4, describes the general principles of temperature measurement, the techniques to be used and gives practical hints such as protective materials to be used in measuring the temperatures of materials which attack the measuring device.

The whole book is well set out with many tables to clarify the descriptions and small diagrams that do not break the continuity of the text. No frightening theory is included and the most difficult part of the book to the inexpert eye would be the part on temperature scales which necessarily involves fundamental equations which must be taken without proof.—J. R. PATTISON.

HEHEMAN, R. F. and AULT, G. M. (Editors). '*High Temperature Materials*'. (Conference held in Cleveland, Ohio, 16–17 April 1957.) 9×6 in., pp.xvi+544. Illustrated. 1959, New York, London: John Wiley & Sons Inc.; Chapman & Hall Ltd. (Price £7.)

KINGERY, W. D. '*Property Measurements at High Temperatures*'. 10×7 in., pp.416. Illustrated. 1959, New York, London: John Wiley & Sons, Inc.; Chapman & Hall Ltd. (Price £6 12*s.*)

KINGERY, W. D. (Editor). '*Kinetics of High Temperature Processes*'. (Report of a Conference, MIT, 23–27 June 1958.) 10½×8 in., pp.xvi+326. Illustrated. 1959, New York, London: Technology Press of MIT, John Wiley & Sons Inc.; Chapman & Hall Ltd. (Price £5 8*s.*)

Although these three books have a common theme, i.e. metallurgy at high temperature, they are written for three different types of reader.

The first edited by Heheman and Ault deals with a series of papers presented at a symposium on recent developments in High Temperature Materials held in April 1957 in Cleveland, Ohio, by the American Institute of Mining, Metallurgical, and Petroleum Engineers. As the future growth of many phases of modern technology depends on the development of adequate high temperature alloys, this symposium aroused considerable interest and papers were presented by leading authorities in the various subjects. The papers were grouped into sections dealing with Cobalt and Nickel Base Alloys, Cermets and Intermetallics, Refractory Metals (Cr, Mo, W, Ta, Nb, Re), Strengthening by Dispersion of Insoluble Particles, Vacuum Melting and its effect on Properties, The Effect of Testing Environment on Properties, and Oxidation Resistance.

Each section contains an excellent review paper on the particular subject and this is supplemented by a series of specialized papers. Most modern applications demanding the highest strength material at very high temperatures call for cobalt and nickel base alloys, sometimes vacuum melted, and these aspects are comprehensively treated. Such materials are, however, nearing the end of their possible development and the material of the future will be chosen from cermets, intermetallics, or the more refractory metals. As the various authors show, all the potential new materials have factors limiting their development. Cermets although having outstanding high temperature rupture strength have very inadequate impact strength despite extensive process research including studies of infiltration techniques and graded structures having free surfaces richer in the bonding metal. Chromium base alloys despite significant improvements in purity still have ductility and impact strength well below that desirable for engineering applications. Molybdenum despite alloy research which has produced outstanding rupture strength even at 1200°C (14 T/in² for 100 h rupture), cannot be adequately protected against oxidation for most of its potential applications. Its usefulness for missiles and rockets is however apparent. It is still difficult to prophesy which if any of these materials, or perhaps W, Ta, Nb, and Re, which are also reviewed, will become the successor to cobalt and nickel base alloys at the highest temperatures. However, the metallurgist concerned with alloy development, and the design engineer on high temperature projects will find this comprehensive survey invaluable in forming an opinion.

The second book by W. D. Kingery on Property Measurements at High Temperatures deals with the factors affecting and methods of measuring material properties at temperatures above 1400°C. It is unnecessary to emphasize the difficulty of accurate measurement of physical, mechanical, and chemical properties at such high temperatures and this book fulfils a very useful function in presenting the various appropriate techniques. There are general chapters on temperature measurement, laboratory refractories, and laboratory furnaces, which serve as an introduction to the various more specialized sections that follow.

The author deals comprehensively with various techniques and physical and mechanical property measurements. Each chapter

contains a general introduction defining the property to be measured and formulating the physics and theory to be used in the experimental techniques. The treatment is most detailed as shown by the inclusion of 100 references for most of the chapters and a total of approximately 1000. This book is for the advanced research worker concerned with the determination of physical properties or for the designer or metallurgist who is interested in such evaluations, and is a most useful compilation.

The third book edited by W. D. Kingery on The Kinetics of High Temperature Processes is once again a compilation of papers presented at a symposium on this subject in June 1958 at Massachusetts Institute of Technology. This particular conference was divided into sections dealing with Imperfections and Diffusion in Non-Metals, Diffusion in liquids and Liquid Solid Reactions, Nucleation and Grain Growth, Sintering and Vitrification, Phase Transformations, Solid–Solid Reactions, and Solid Gas Reactions. Each section is followed by a report of the discussion which took place on the presentation of various papers. There is little unifying thread to the various papers which are an attempt to present the results of current specific investigations in these fields in order to pave the way for future generalizations. Accordingly the book is only of interest to the specialist fully conversant with these fields, and would be of little value for engineers or metallurgists requiring a general book on the kinetics of high-temperature processes.—H. C. CHILD.

MAWSON, P. '*A Vision of Steel. The Life of G. D. Delprat*'. 8½×5½ in., pp.xvii+269. Illustrated. 1958, Melbourne: F. W. Cheshire. (Price £2 2*s*.)

Guillaume Daniel Delprat, the son of a chaplain at the Dutch Court, was born in Delft in 1857. He came to Scotland as a young engineering apprentice, took his degree in Holland, and became a mine manager in Spain where, in a characteristic adventure, he discovered and opened up a rich silver mine abandoned since Roman times. Delprat inspected mines in Mexico, Norway, and Canada but it was in Australia that he found fame. Invited in 1898 to be general manager of the Broken Hill Proprietary Company, then a silver, lead, and zinc producer, it was his vision and enterprise which eventually transformed the Company into a large-scale producer of iron and steel. When he left the Company in 1921, it had become virtually the Australian iron and steel industry. Delprat died in 1937 at the age of eighty. This well-written biography, with its overtones of turbulent industrial development, is by his daughter, Lady Mawson. It is a worthy memorial to a remarkable man, but steelmen in Australia seeking his monument need only look around them.—M. L. PEARL.

SEARLE, A. B. and GRIMSHAW, R. W. '*The Chemistry and Physics of Clays and Other Ceramic Materials*'. 3rd ed. 9×6 in., pp.942. Illustrated. 1959, London: Ernest Benn Ltd. (Price £6 6*s*.)

This is the third edition of a well-known ceramic text book, which had become very much out of date and has now been entirely revised and rewritten. The revision, has been mainly the work of the junior author and to some extent reflects his own interests and experience although the character of the earlier editions has been preserved to some extent. No fewer than three chapters on crystal structure, one on the principles and two on the structures of crystalline species encountered in ceramics, have been included. In these the authors appear to lean somewhat heavily on certain well-known text-books on this subject. In a chapter on phase diagrams, methods of interpreting binary and ternary diagrams and of calculating the relative proportions of the various phases present are explained. The remaining chapters deal with such topics as the identification of minerals, the chemical and mineralogical constitution of ceramic raw materials, the influence of water on ceramic materials and the chemical and physical changes which occur during firing.

The task which the authors have undertaken is, of course, a formidable one and perhaps inevitably the treatment tends to be somewhat uneven. In certain sections also the personal prejudices of the junior author are apparent. For example, the disordered form of kaolinite found in many fireclays is claimed throughout to be a distinct mineral species, livesite, although so far as the reviewer is aware, this has not yet been accepted by mineralogists. There are a number of errors and inaccuracies. Thus on page 739 the authors describe a method of calculating the specific gravity of a mixture of minerals that is based on the assumption that the densities are additive. This is an elementary error. As older metallurgists who were brought up on the early edition of Desch's *Metallography* will know, it is volumes which are additive, not densities. In Fig.X.41 on page 589, the solid-phase distribution shown for the system FeO–Al_2O_3–SiO_2 is in error, since, it shows fayalite to co-exist with mullite. The existence of a tie-line joining SiO_2 and $FeO.Al_2O_3$ (hercynite) was established many years ago and more recently it has been shown that iron cordierite, whose composition lies on this line, also occurs in the system. The first product of the attack of ferrous oxide on firebricks is thus iron cordierite not fayalite.

Such inaccuracies are unfortunate in a book which, the authors hope, will cover the requirements of students to University degree level and to the level of the professional qualifications of the Institute of Ceramics. Such criticisms apart, the book should prove a useful addition to the as yet rather inadequate literature of ceramic technology.—J. H. WHITE.

SÉFÉRIAN, D. '*Metallurgie de la Soudure*'. 9½×6 in., pp.xviii+393. Illustrated. 1959, Paris: Dunod-Editeur. (Price 5800 Fr.)

This book is an introduction to the metallurgy of welding ferrous metals written by a pioneer in the academic and practical branches of welding technology in France for the benefit of welding engineers and metallurgists. The book covers the more classic and established aspects of metallurgy and welding metallurgy, with particular reference to the metal arc process.

The first part deals with the metallurgical aspects of welding steels, and after a brief description of various welding processes explains very comprehensively the significance of the iron–carbon diagram and of isothermal and continuous cooling transformation diagrams. This is followed by a discussion of problems associated with coating formulation, slag-metal relationships, and hot and cold cracking. The second part of the book deals with the weldability of plain carbon, low alloy, and austenitic stainless steels and introduces the reader to the concept of the Schaeffler's diagram and the effects of interalloying, as a result of dilution, when welding dissimilar metals. Perhaps the most valuable chapter is the last which deals with the weldability of the low-alloy, chromium–molybdenum steels, and contains much information of interest to the welding metallurgist. Though the subject matter of the book does not cover the more complex pioncering problems of welding, it is a very welcome contribution consolidating the established knowledge on welding metallurgy and will be of value to all French-speaking metallurgists with an interest in welding. The recent death of the author is a severe loss to the whole welding industry.

—M. C. T. BYSTRAM

SHVARTZ, G. and KRISTAL, M. '*Corrosion of Chemical Apparatus*'. [Translation from the Russian, '*Korroziya Khimicheskoi Apparatury*', 1958.] 9×6 in., pp.iv+250. Illustrated. 1959, New York, London: Consultants Bureau Inc.; Chapman & Hall Ltd. (Price £3.)

The title of this book gives no real indication that it is, in fact, a specialized treatise on intercrystalline and stress-corrosion cracking. With 219 references to the literature it is largely an extended bibliography. As such it is a valuable source of information to the specialist but, with the exception of Chapters V and VI on Protection and Testing, no easy guide for the engineer or student — Chapter V, however, covers a great deal of valuable practical information on design and construction to avoid stress corrosion and should be widely read by plant engineers. The authors summarize a vast amount of published data, mostly without detailed critical evaluation, though allowing personal preferences to appear in the conclusions at the ends of chapters. References are not always accurate and some terms and symbols are unusual, as, for example, the use of D, apparently as Rusian symbol for Cu. The expressions 'bubble steel' and 'bubble-free steel' are refreshingly different to British readers, but care is needed in interpretation of heat-treatment terms, normally given rather different usage in British literature. The authors have carried out a considerable task with thoroughness, and the results will be of undoubted value and interest, not only as such, but as giving a clear indication of much active and effective Russian work in the fields covered.—H. T. SHIRLEY.

WUSATOWSKI, Z. (Editor). '*Warmofen für Walzwerke und Schmieden*'. [German translation from Polish of '*Piece Grzewize Walcownicze i Kuznicze*]. 9½×6½ in., pp.612. Illustrated. 1959, Berlin: VEB Verlag Technik. (Price DM.60.–)

This book deals in encyclopaedic detail with all aspects of heating furnaces, both the fundamental calculation and design, methods of construction, choice of different types of furnace, special details of construction and waste heat recovery. It has copious illustrations, of just the right kind, not giving complete working details but sufficient to show the proportions and rough dimensions. In the section on recuperators, the general principles of cross flow, parallel flow, and counterflow are illustrated diagramatically and with gas temperature curves: then good working diagrams are given for ceramic recuperators of two types of construction, metallic needle recuperators and tubular steel recuperators; proper working layouts and details of the design of the important elements are given; while the full calculation of recuperators for particular furnaces are dealt with in the later chapter where calculations are carried right through. Regenerators are dealt with in equal detail, particularly for the soaking pit. There is a long chapter on the peculiarities of design of each type of heating furnace, containing for example 16 pages on the soaking pit, and over 20 pages on pusher furnaces. The large annular tunnel kiln, or rotating hearth furnace, receives more attention than is usual in an English text-book, because this type of furnace is in more common use on the continent.

It can thus be said that the book is a really comprehensive statement of the present state of knowledge of all aspects of reheating furnaces, but it does of course show up those points on which further research is still necessary, particularly the gas flow patterns in such furnaces, the study of flame length, and the effects of luminous radiation and of recirculation. The accurate calculation of the heat balance in stages along the length of a furnace, particularly for the pusher type furnace where the soaking zone must be very uniform in heat transfer rate, taking account of longitudinal radiation, delayed combustion, and recirculation as mechanisms of making the temperature of the flame more uniform has yet to be done, and so also has the problem of calculating such a furnace during the period that a different thickness of block is moving down it. However, there is no question that this book provides the best possible background for such calculations by its encyclopaedic statement of present knowledge.—M. W. THRING.

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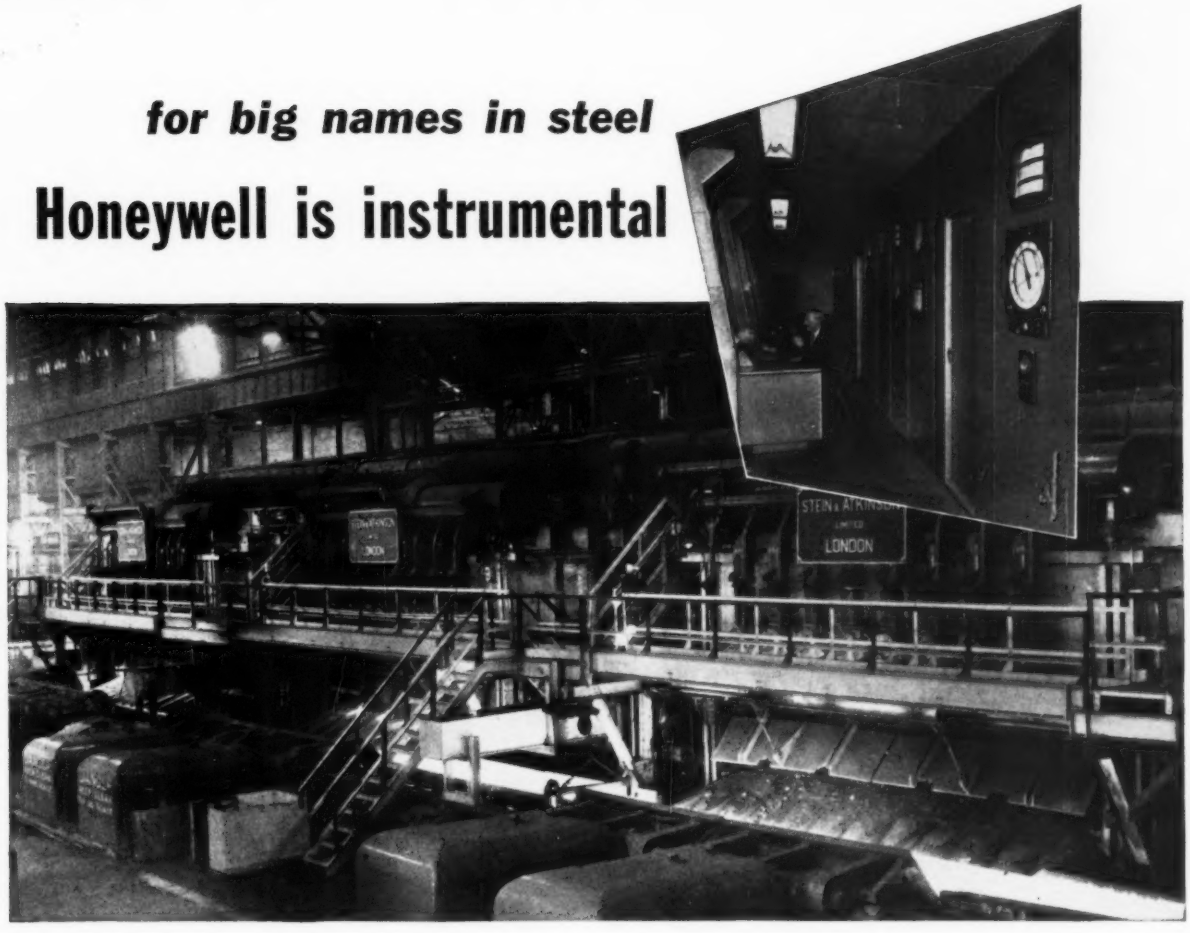

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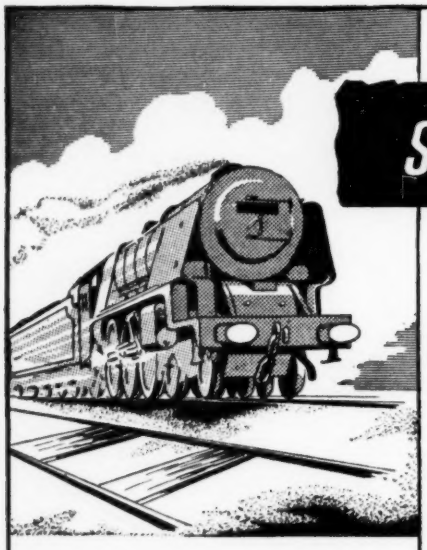

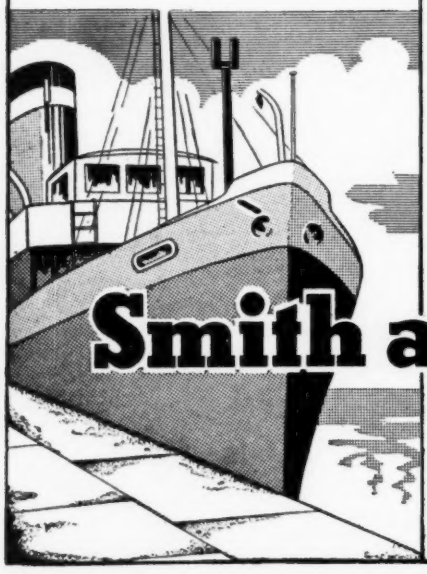

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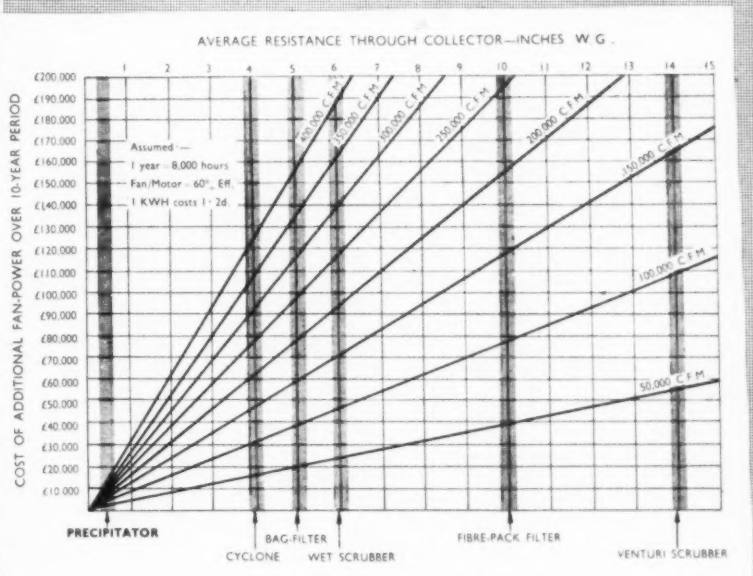

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Electrical Aids in Industry

Data Sheet **No. 9**

Lighting-3

Data Sheet No. 7 dealt with some actual applications of factory lighting. Further applications are given here.

Drawing Offices

It is fair to say that in no part of a factory is good lighting more important than in the drawing office. The draughtsman's task is extremely exacting and unless the illumination is up to required standards, mistakes, loss of time and greater fatigue will result.

The essential requirements are:

High value of illumination
(*minimum of 30 foot-candles on the boards*)
Absence of shadows
Absence of reflection

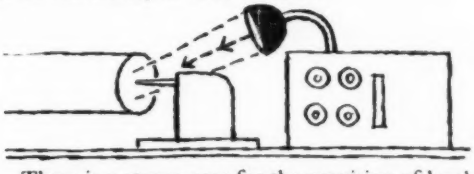
One of the major problems is the reflection of the light sources by shiny tracing paper, instruments, set-squares, etc., and particularly by the extra-hard pencil leads often used. Another problem is that caused by the shadows ahead of T-squares and by the variety of angles at which drawing boards are set.

Fluorescent lighting is particularly suitable because of its comparative freedom from shadow, its natural colour and because it can be localised with respect to drawing boards to avoid reflections while at the same time giving enough light upward and sideways to satisfy the general lighting requirements of the office.

A lighting solution which has been successfully employed for tracing is to light from beneath and through the paper which is fixed on to a translucent panel, thus eliminating the problems of shadow and reflection.

Machine Shops

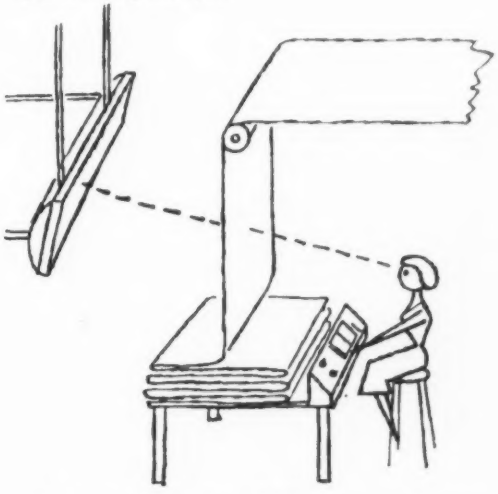
The problems of machine-shop lighting vary so widely that it is impossible to lay down rigid rules which are applicable to all types of machine. Much of the design of such lighting systems must therefore be a matter of individual application. Certain maxims, however, have proved in practice to be satisfactory in various trades.



There is a strong case for the provision of local lighting on many machines to enable the direction of light to be varied to suit the work, or to boost the illumination for fine work.

In shops employing certain machine tools, particularly circular saws, the possibility of stroboscopic effects can be avoided by splitting lamps among the phases of a three-phase supply or by using twin lamp fittings with a split-phase circuit.

Where safety goggles are used, extra illumination should be provided to compensate for the reduced light reaching the eyes.



Silhouette inspection of fabrics or profiles can often be used to advantage by placing a light source behind the material to be inspected — on the lines of the back-lighting already referred to for tracing in the drawing offices.

In general, machine-shop lighting is essentially an empirical science, based largely on a combination of general and local lighting, which offers immense scope for ingenuity.

Outside Lighting

The outside precincts of a factory are often much neglected. No special rules can be suggested for lighting these areas, but speed, efficiency and safety are all dependent on adequate outside illumination during the hours of darkness.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each or 9/- post free) are available—"Lighting in Industry" is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity, including one on industrial lighting. Ask for a catalogue.

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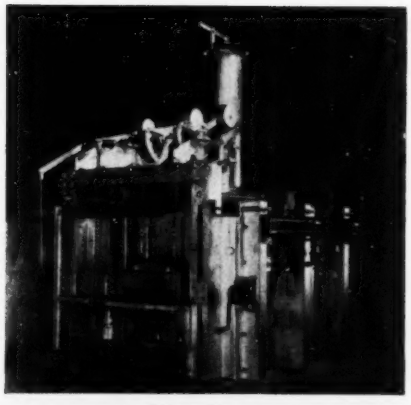

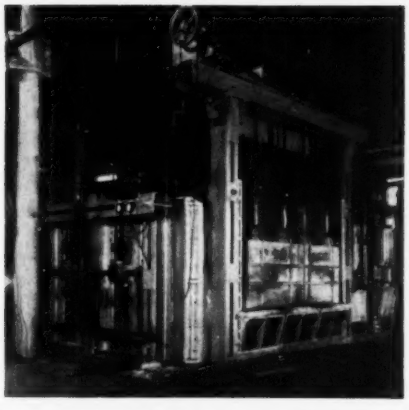

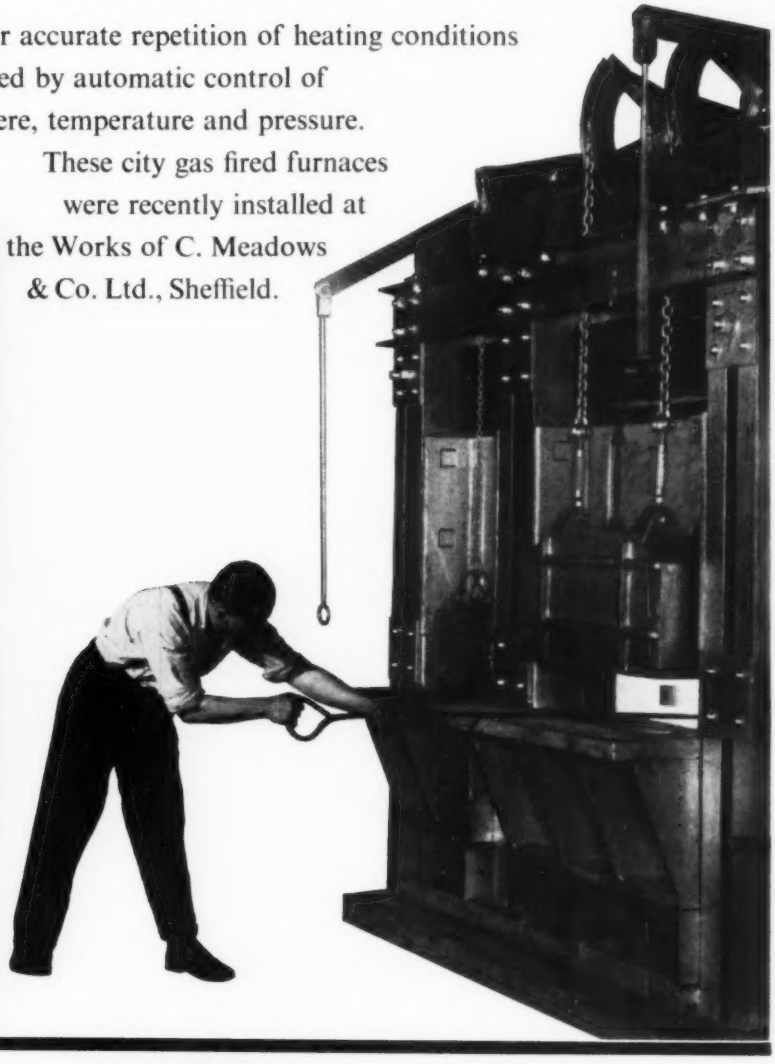

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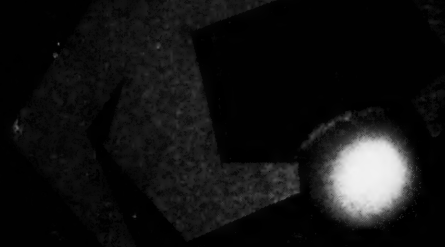

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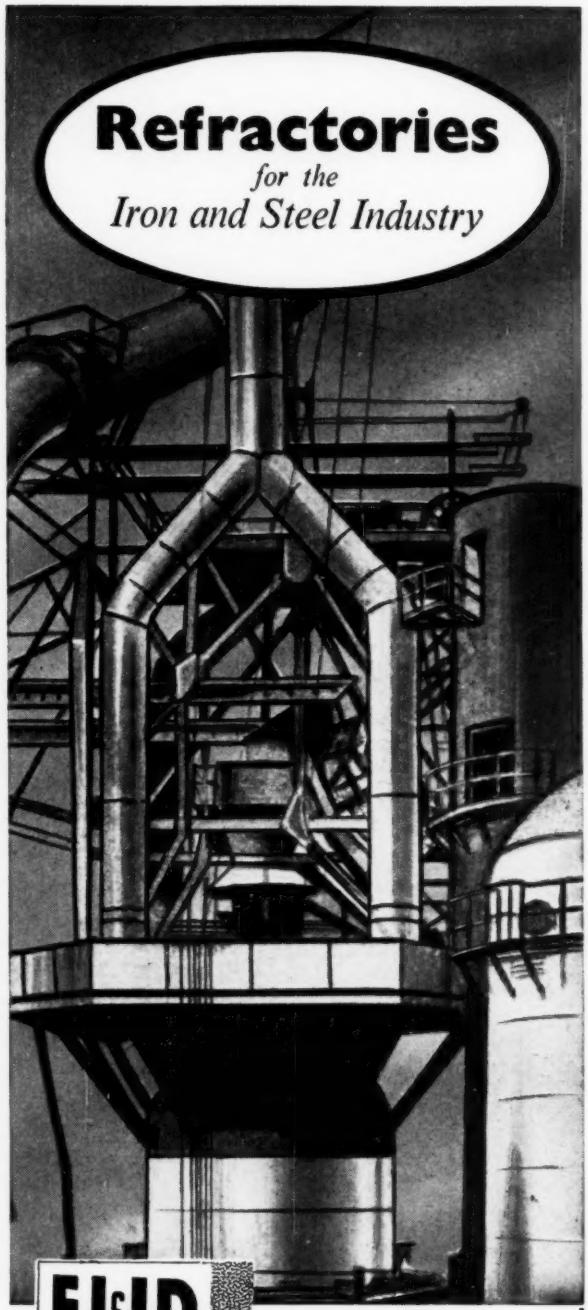

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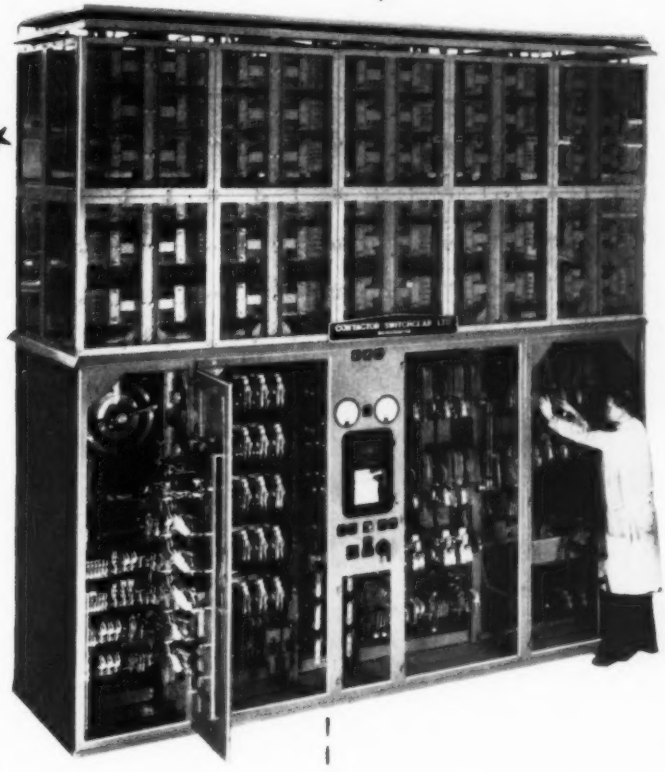

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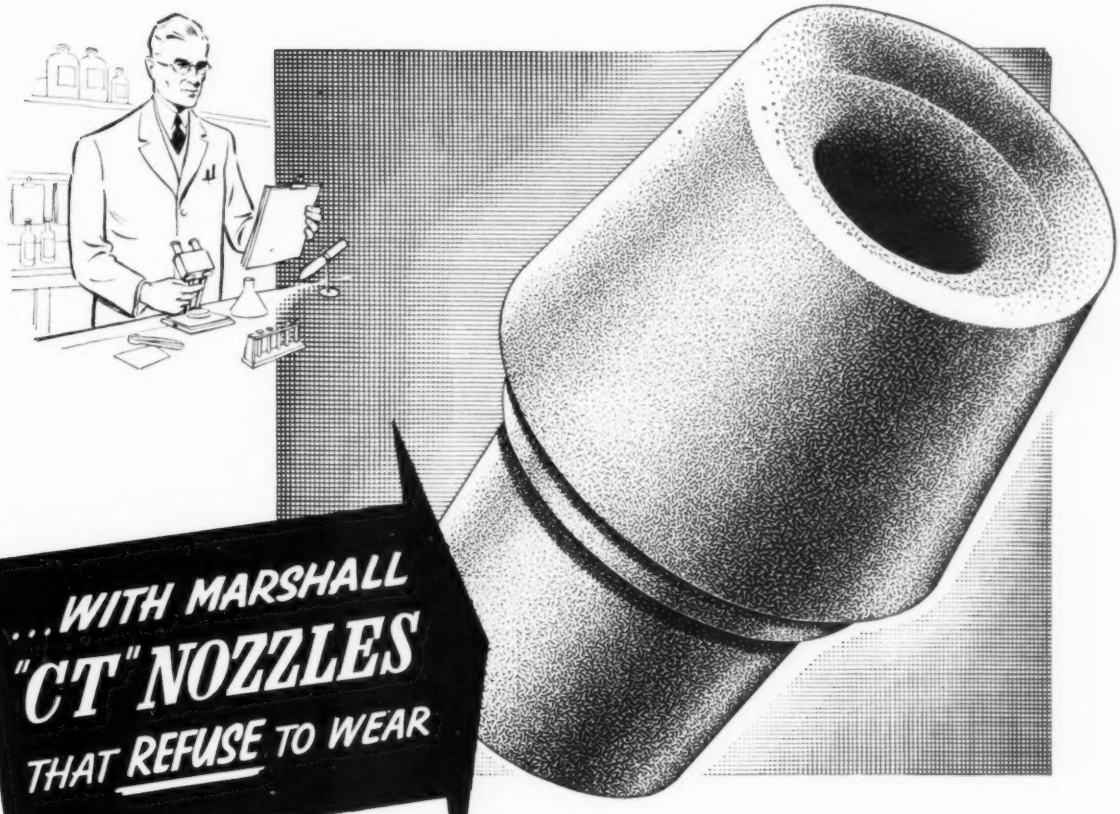

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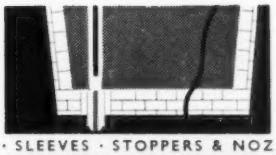

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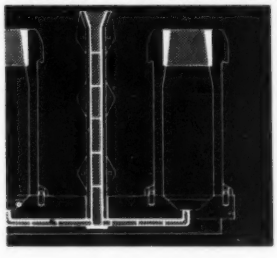

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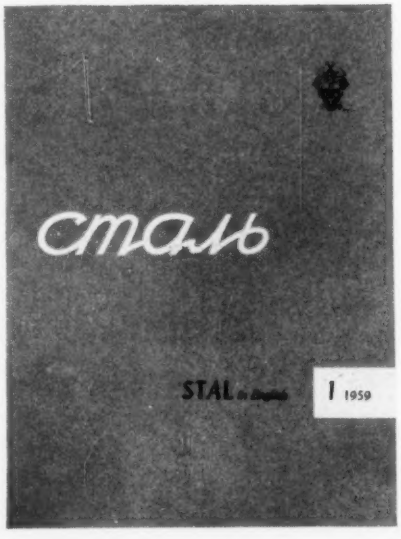

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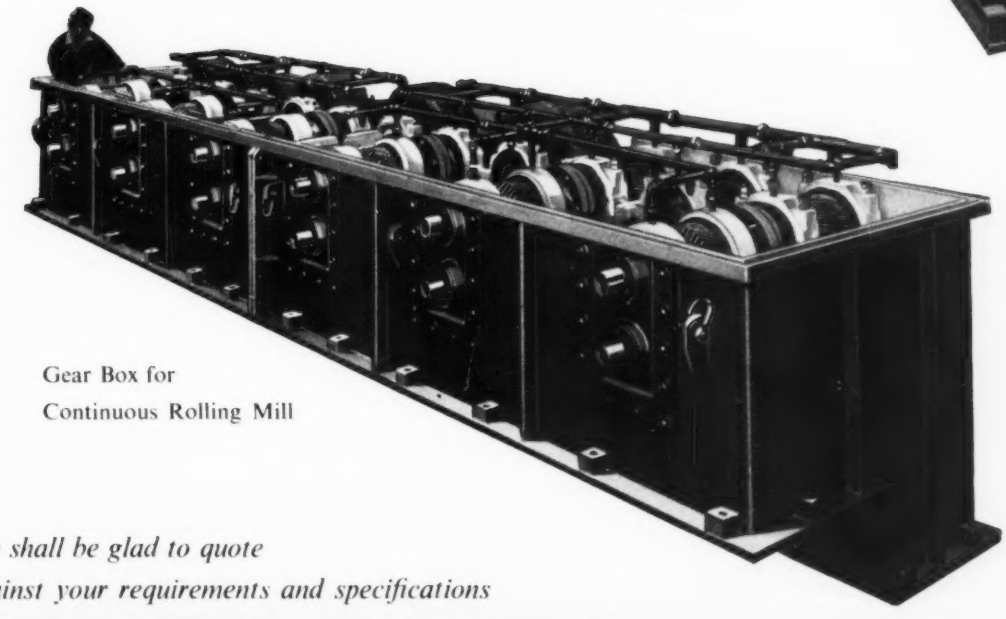

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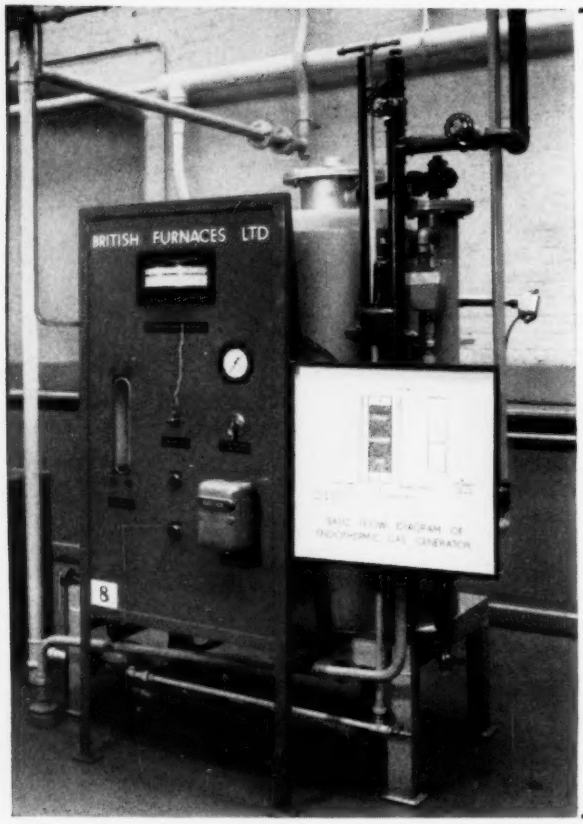

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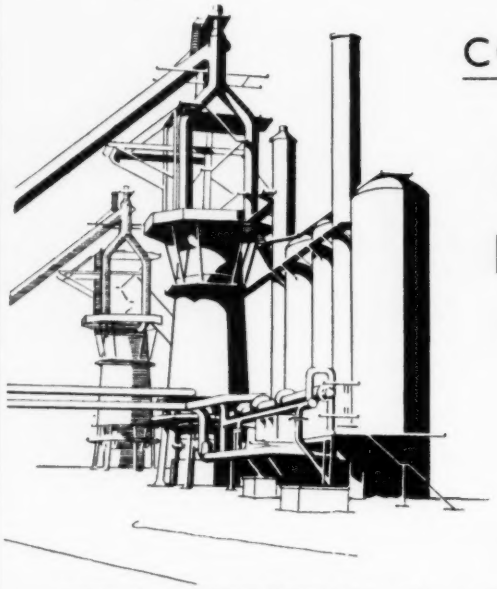

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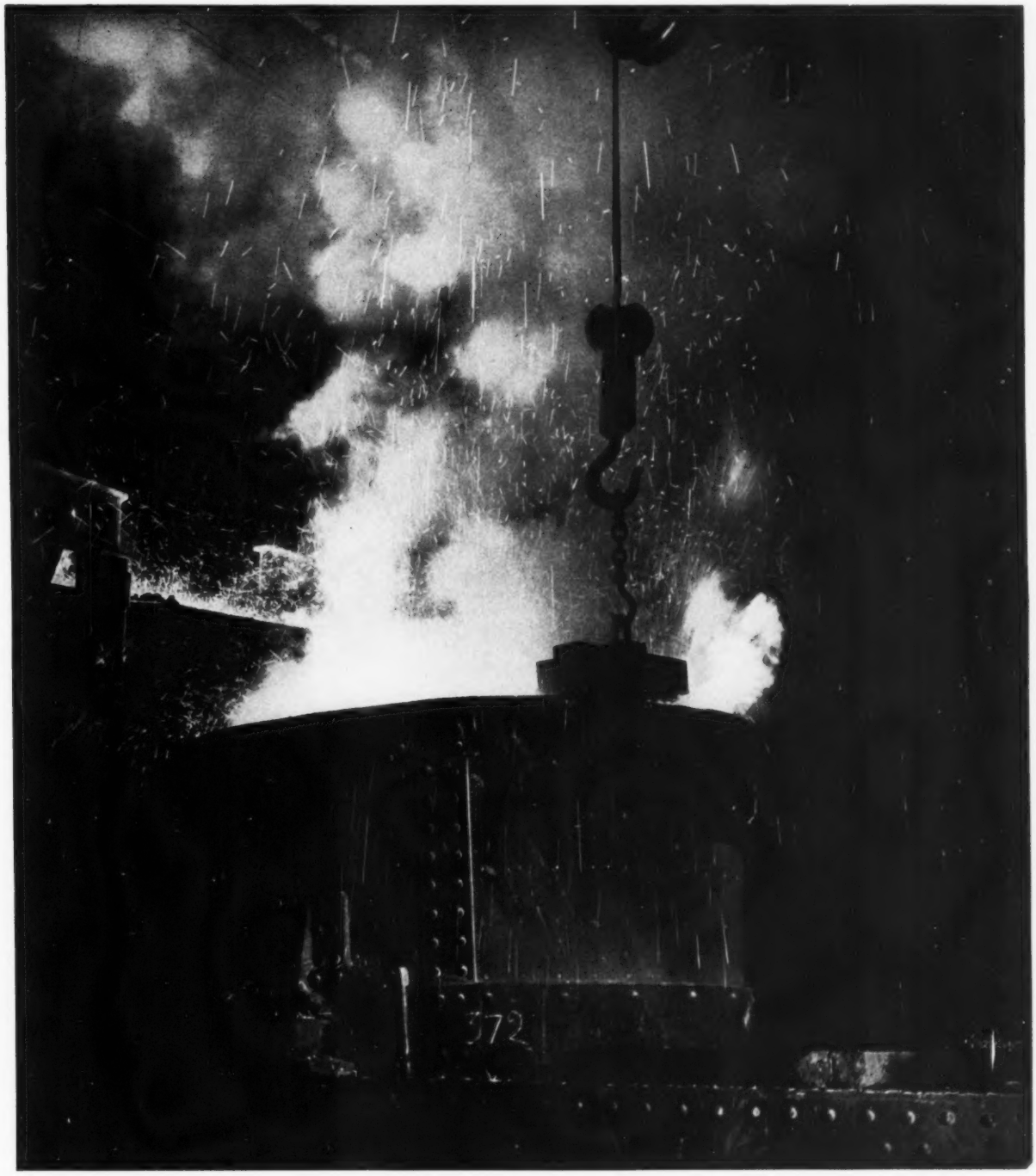

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Adamson-Alliance Co. Ltd. . . . 2
Adamson, Joseph, and Co., Ltd. . 52
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Ashmore, Benson, Pease, & Co. Inside Back Cover
Associated Electrical Industries Ltd. 54, 66

Baker Platinum Division 34
Barrow Ironworks Ltd. . . . . —
Beardmore, William, & Co., Ltd. . —
Bigwood, Joshua, & Sons, Ltd. . —
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Bradley & Foster Ltd. . . . . —
Brightside Foundry & Engineering Co., Ltd., The 60
British Acheson Graphite Ltd. . —
British Electrical Development Association 77
British Furnaces, Ltd. 86
British Iron & Steel Federation, The 18, 19
British Paints, Ltd. . . . . —
British Rollmakers Corporation, Ltd. 67
British Thomson-Houston Co., Ltd., The . . . . . —
British Timken: Division of the Timken Roller Bearing Co. . . 20
Brookhirst-Igranic Ltd. . . . . —
Brown Bayley Steels, Ltd. . . 87
Burn Fireclay Co. Ltd., The . . —
Bushing Co. Ltd., The . . . 59

Carblox Ltd. . . . . —
Chemical Construction (G.B. Ltd. . 40
Colvilles, Ltd. 28
Consett Iron Co. Ltd. 47
Constables (Matlock Quarries) Ltd. . —
Contactor Switchgear, Ltd. . . 81
Coppee Co. (Gt. Britain) Ltd., The . 26
Craven Bros. (Crane Division), Ltd. . —
Crofts (Engineers) Ltd. . . . . —
Crooks, L. E. . . . . —

Davy & United Engineering Co. Ltd. . 72
Demag . . . . . —
Dewhurst & Partner, Ltd. . . . 35
D.M.M. Machinery, Ltd. . . . . —
Dyson, J. & J. Ltd. Inside Front Cover

Edwards High Vacuum Ltd. . . . —
Electric Resistance Furnace Co. Ltd. —
Electroflo Meters Co. Ltd. . . . —
Engelhard Industries Ltd. . . . 34
English Electric Co. Ltd., The . . —
English Steel Rolling Mills Corporation, Ltd. 22

Foster, Henry, & Co. Ltd. 37
Foster Instrument Co. Ltd. . . —
Fuller's Earth Union Ltd., The . —

Gas Council, The 30, 31
General Electric Co. Ltd., The . . 50
General Refractories, Ltd. . . . —
Gibbons Brothers, Ltd. . . . . —
Gibbons (Dudley) Ltd. 63
Green, E., & Son, Ltd. . . . . —
Guest Keen Iron & Steel Co. Ltd. . 76
Guest, Keen & Nettlefolds, Ltd. . 14
G.W.B. Furnaces, Ltd. 15

Hadfields, Ltd. . . . . —
Head, Wrightson, Iron & Steel Works Engineering, Ltd. . . . . —
Head, Wrightson & Co. Ltd. . . 55
High Speed Steel Alloys Ltd. . . —
Holmes, W. C. & Co., Ltd. . . 29
Holset Engineering Co., Ltd. The . 42
Honeywell-Controls, Ltd. . . . 73
Howden, James & Co., Ltd. . . 25
Hudswell Clarke & Co. Ltd. . . 56
Hunslet Engine Co. Ltd. . . . —
Huntington, Heberlein & Co. Ltd. . —

Ilford, Limited 61
Imperial Chemical Industries Ltd. . —
Industrial & Metallurgicial Equipment Ltd. 82
International Combustion Products Ltd. 7
International Construction Co. Ltd., The 24

Johnson's Rolls Ltd. . . . . —
Johnson Matthey & Co. Ltd. . . 45

Kelvin Hughes Ltd. 46
Kestner Evaporator & Engineering Co. Ltd. 82
King, Geo. W., Ltd. . . . . —
Kingscliffe Insulating Products, Ltd. —

Lamberton & Co. Ltd. Outside Back Cover
Lanarkshire Steel Co. Ltd., The . —
Lancashire Steel Manufacturing Co. Ltd. 64
Laurence, Scott & Electromotors Ltd. —
Lodge-Cottrell, Ltd. 32
Loewy Engineering Co. Ltd., The . 16
Lysaght's John, Scunthorpe Works Ltd. 57

Marshall, Thomas, & Co. (Loxley) Ltd. . 83
Metallurgical Engineers Ltd. . . —
Metropolitan Vickers Electrical Co. Ltd. . . . . —
Mitchell Engineering Ltd. . . 48, 49
Mobil Oil Co. Ltd. 5
Mond Nickel Co. Ltd. . . . . —
Moorwood, John M., Ltd. . . . —
Morgan Refractories Ltd. . . . —
Morgardshammars Mekaniska Verkstads AB 6
Moxey Ltd. . . . . —

National Industrial Fuel Efficiency Service . . . . . —
Newell, Ernest, & Co. Ltd. . . —
Newton, Chambers & Co. Ltd. . . —

Oughtibridge Silica Firebrick Co. Ltd. . 68

Pantin W. & C., Ltd. 27
Park Gate Iron & Steel Co. Ltd. . —
Parsons, C. A. & Co. Ltd. . . . —
Pearson, E. J. & J., Ltd. . . . 80
Philips Electrical Ltd. . . . . —
Pickford Holland & Co. Ltd. . . 58
Power-Gas Corporation Ltd., The Inside Back Cover
Press, William, & Son Ltd. . . —
Priest Furnaces Ltd. 12

Reavell-Fahie Ltd. 53
Rawlplug Co. Ltd., The 4
Research & Control Instruments Ltd. —
Richardsons Westgarth & Co. Ltd. . —
Robertson, W. H. A. & Co., Ltd. . 36
Rust-Oleum Corporation . . . . —

Salem Engineering Co. Ltd. . . . —
Schloemann . . . . . —
Senior Economisers Ltd. . . . 21
Shell-Mex & B.P., Ltd. . . 38, 39
Sheppard and Sons Ltd. . . . 84
Simon-Carves, Ltd. 75
Skefko Ball Bearings Co. Ltd., The . —
Smith, John (Keighley), Ltd. . . —
Smith & McLean Ltd. 74
Smith, Thomas & Sons (Rodley) Ltd. 10
Spencer-Bonecourt-Clarkson Ltd. . 9
Stanton Ironworks Co. Ltd., The . —
Stedall & Co. Ltd. . . . . —
Steel Co. of Wales, The . . . 41
Stein & Atkinson, Ltd. . . . . —
Stein, John G. & Co. Ltd. . . . —
Stephens Silica Brick Co. Ltd. . . 78
Stewarts & Lloyds, Ltd. 13
Stillite Products Ltd. 51
Strachan & Henshaw Ltd. . . . —
Sturtevant Engineering Co. Ltd. . 23
Summerson, Thos. & Sons, Ltd. . 44
Superlite Building Materials Ltd. . —
Swann, Rateliffe & Co. (Brassington) Ltd. . . . . —

Tattersall & Son Ltd. 86
Thermal Syndicate Ltd. . . . . —
Thomas (Richard) & Baldwins Ltd. . —
Thompson L'Hospied & Co. Ltd. . 11
Thornton, B., Ltd. 85

Union Carbide Ltd. 3
United Coke & Chemicals Co. Ltd. . —
United Steel Companies Ltd. . . —

Vaughan, Edgar, & Co. Ltd. . . . —
Visco Engineering Co. Ltd. . . 43

Ward, Thos. W., Ltd. . . . . —
Warner & Co. Ltd. 65
Wellman Smith Owen Engineering Corporation Ltd., The 1
West Hunwick Silica & Firebrick Co. Ltd. . . . . —
West Instruments Ltd. 80
Whitehead Iron & Steel Co. Ltd. . 62
Wild Barfield Electric Furnaces Ltd. —
Willan, G. L. Ltd. 8
Wincott, G. P. Ltd. 79
Woodall-Duckham Construction Co. Ltd. 70
Wragg, Thos., & Sons Ltd. . . 17

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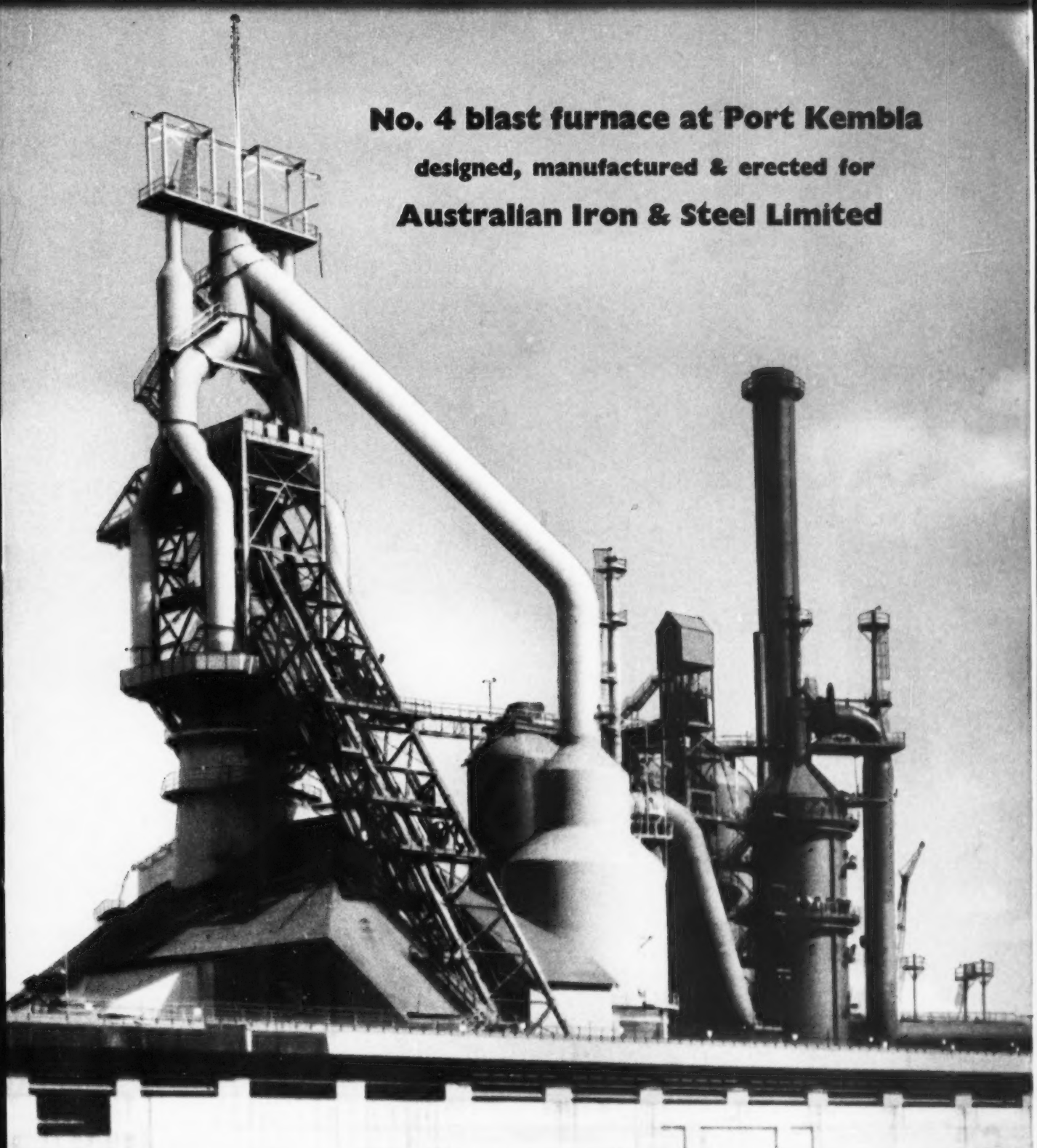

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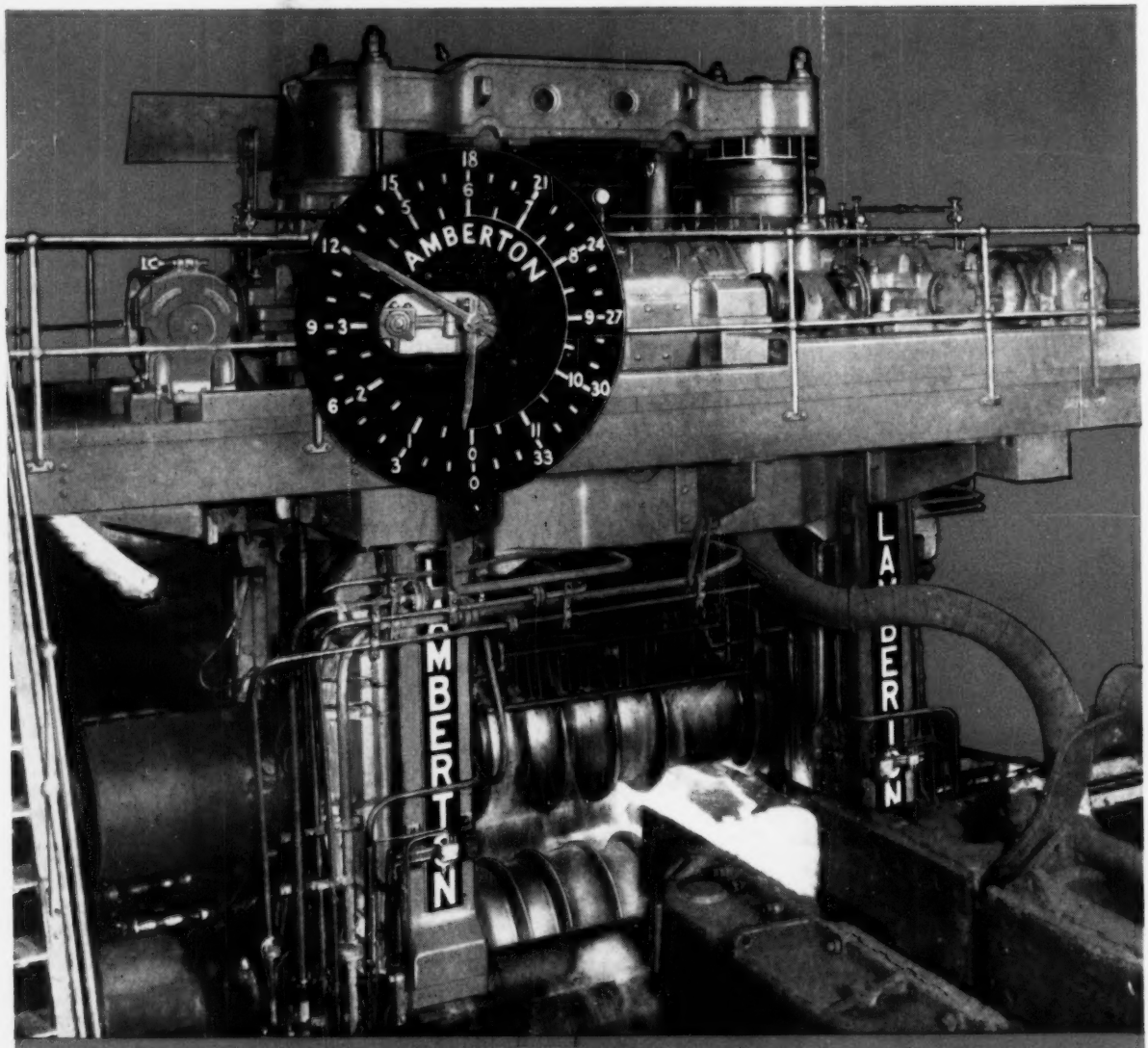

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